

# Recent PHENIX Heavy Flavor Result

Sanghoon Lim  
Yonsei University  
for the PHENIX collaboration

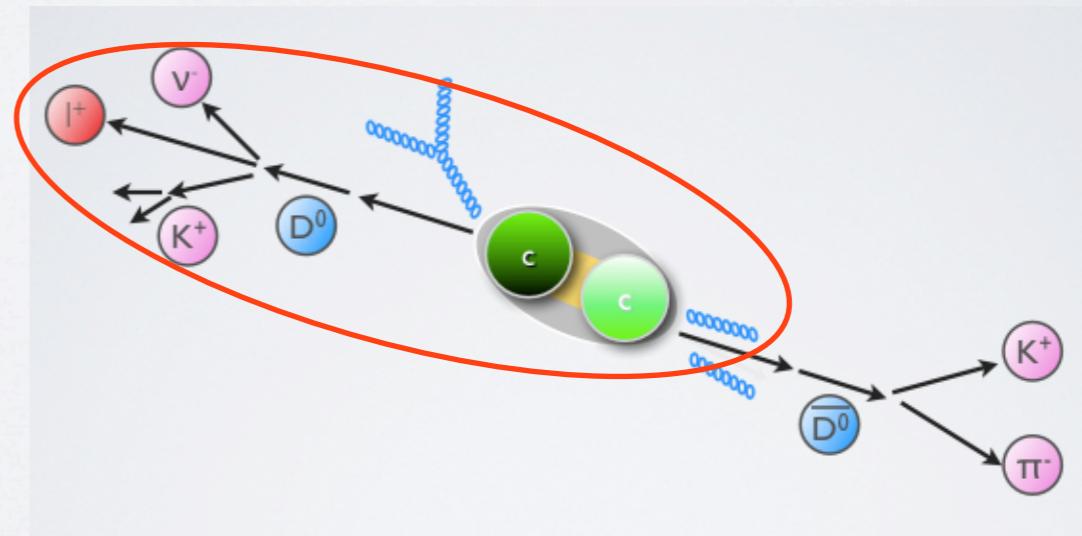
GHP APS 2013  
Denver

# Studying open heavy flavor

- p+p collisions
  - test pQCD calculations
  - baseline for heavy ion collisions
- Heavy ion (Cu+Cu, Au+Au) collisions
  - probe effects of the strongly interacting hot medium
- d+Au collisions
  - quantify cold nuclear matter effects
- PHENIX has suitable design for single lepton measurements

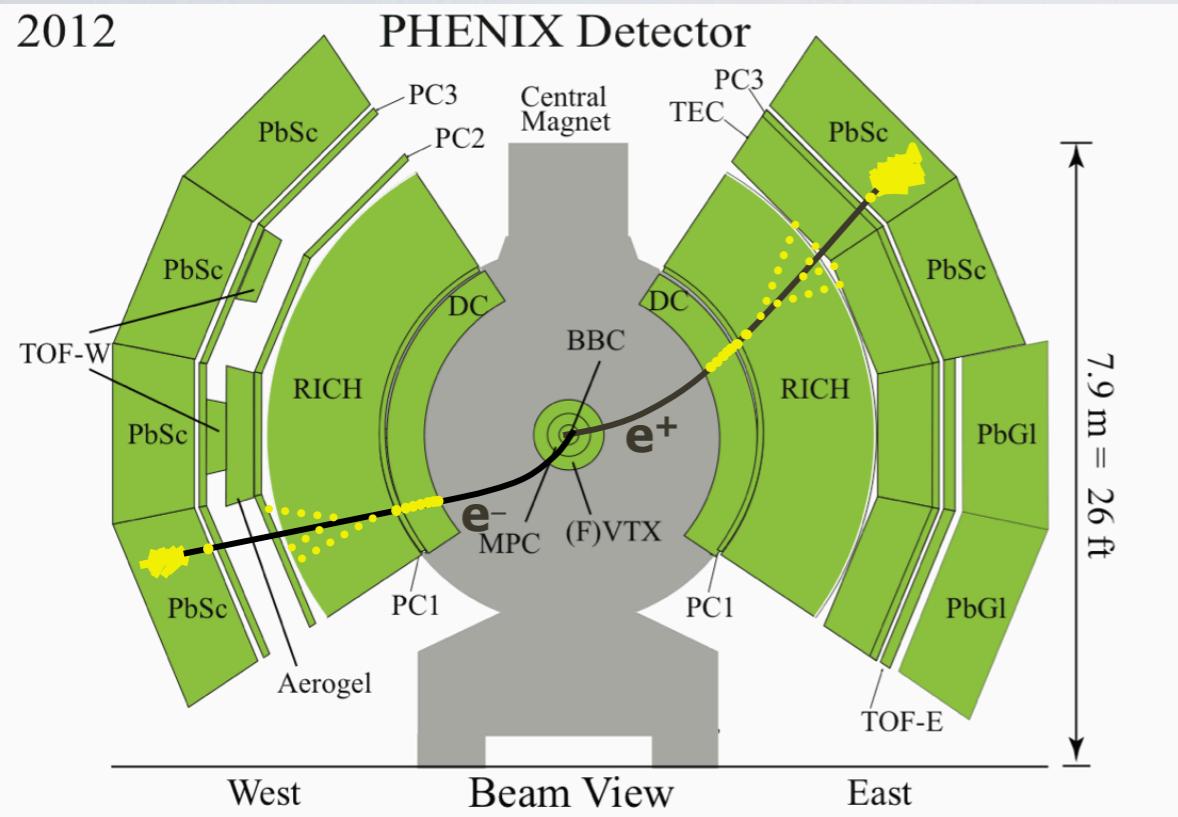
## Semi-leptonic decay

- lepton triggered measurement( $e, \mu$ )  
(statistical background subtraction)



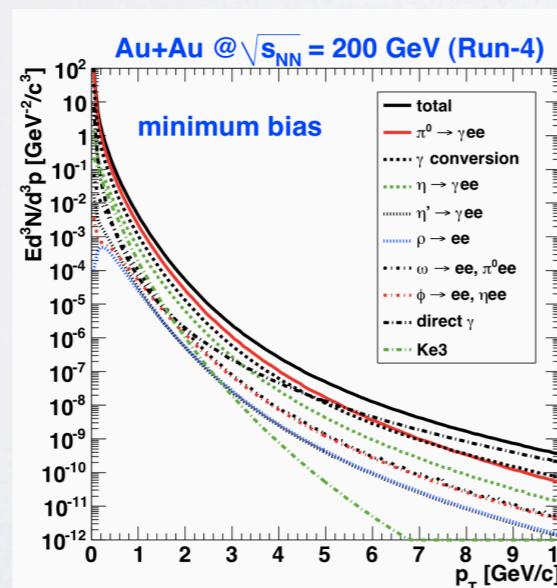
# Electrons at mid-rapidity (Central arm)

2012



- kinematic range
  - $|\eta| < 0.35$
  - $\Delta\varphi = \pi$
- Detectors
  - DC & PC for tracking
  - RICH for electron ID
  - EMcal for energy of electron

- Cocktail method
  - simulate photonic background with measured spectra of hadrons
  - large systematics
  - $\pi^0$  Dalitz
  - conversion  $\gamma$
  - direct  $\gamma$  &  $Ke^3$
  - $J/\Psi, \Upsilon, DY$



- Converter method
  - using photon converter (1.68%  $X_0$ )
  - increase photonic background and statistically limited

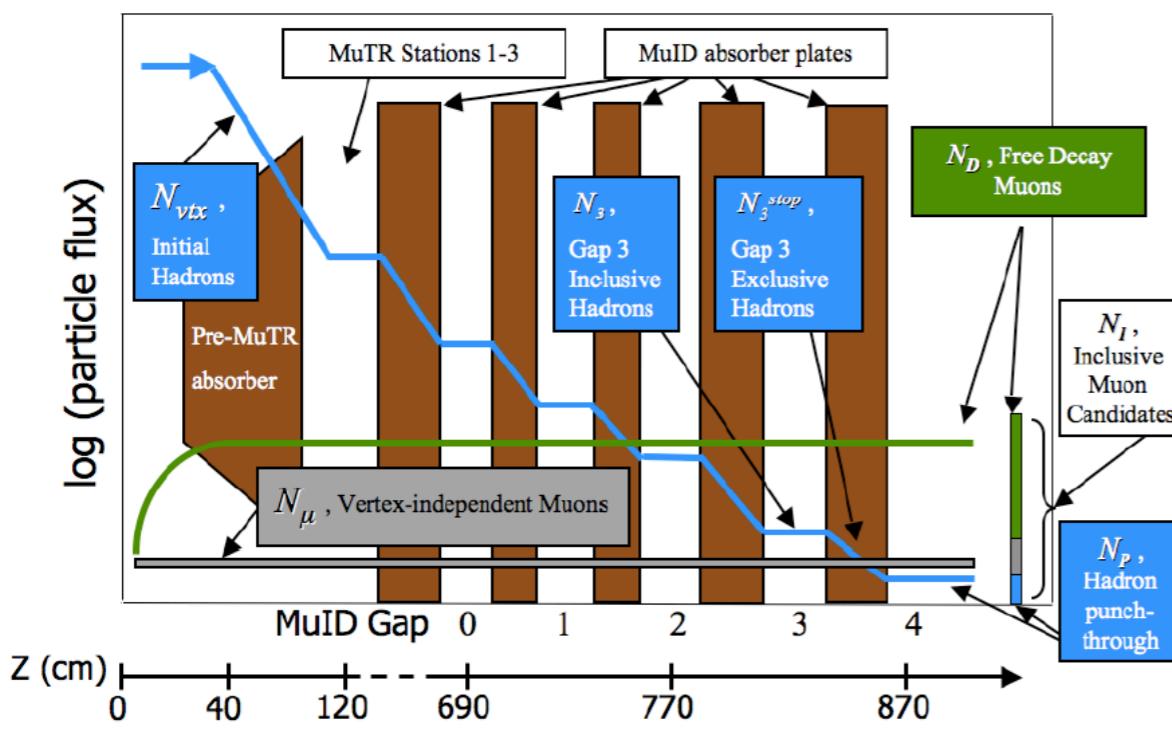
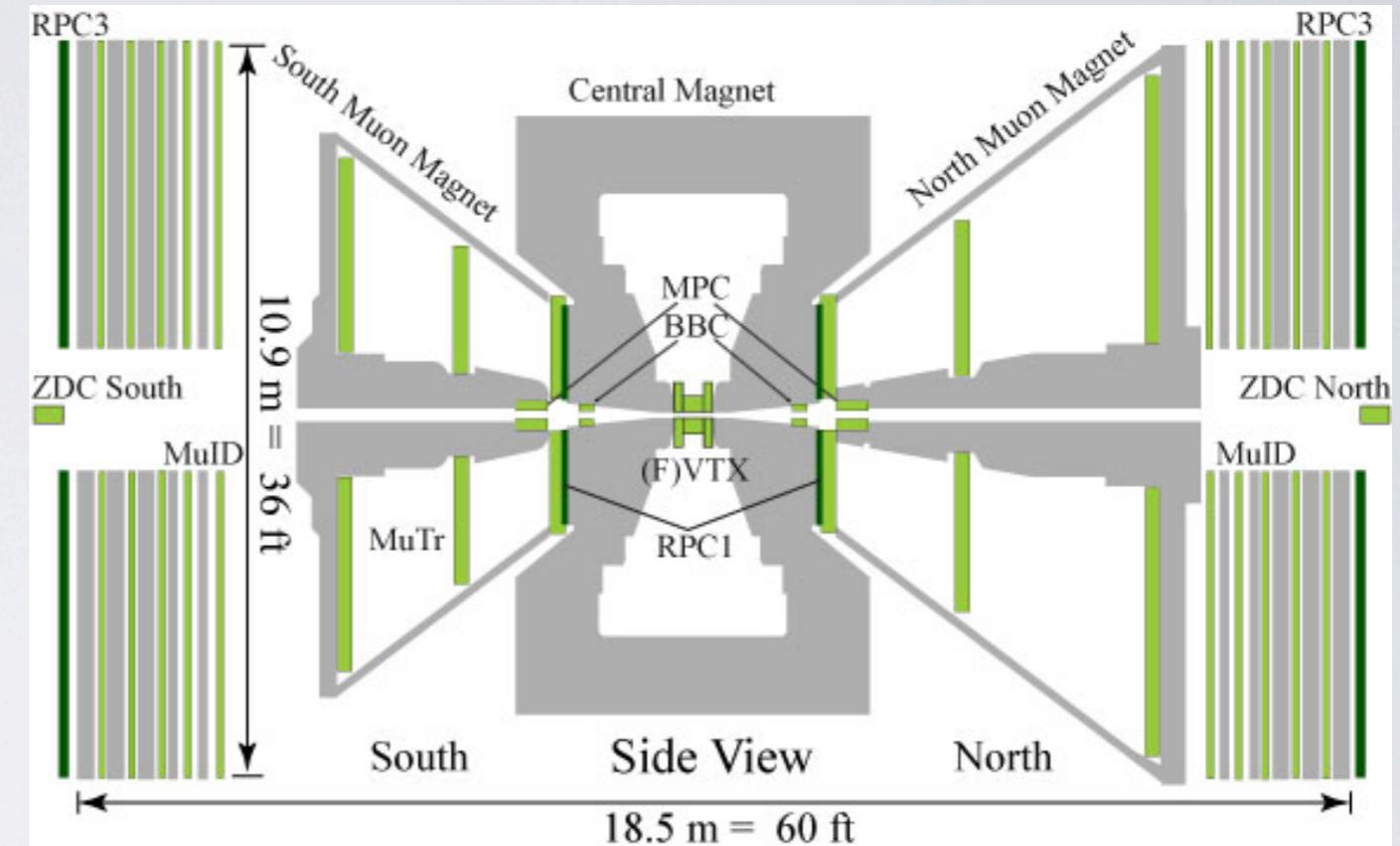
$$N_e^{conv-out} = N_e^\gamma + N_e^{non-\gamma}$$

$$N_e^{conv-in} = R_\gamma N_e^\gamma + (1 - \epsilon) N_e^{non-\gamma}$$



# Muons at forward-rapidity (Muon arm)

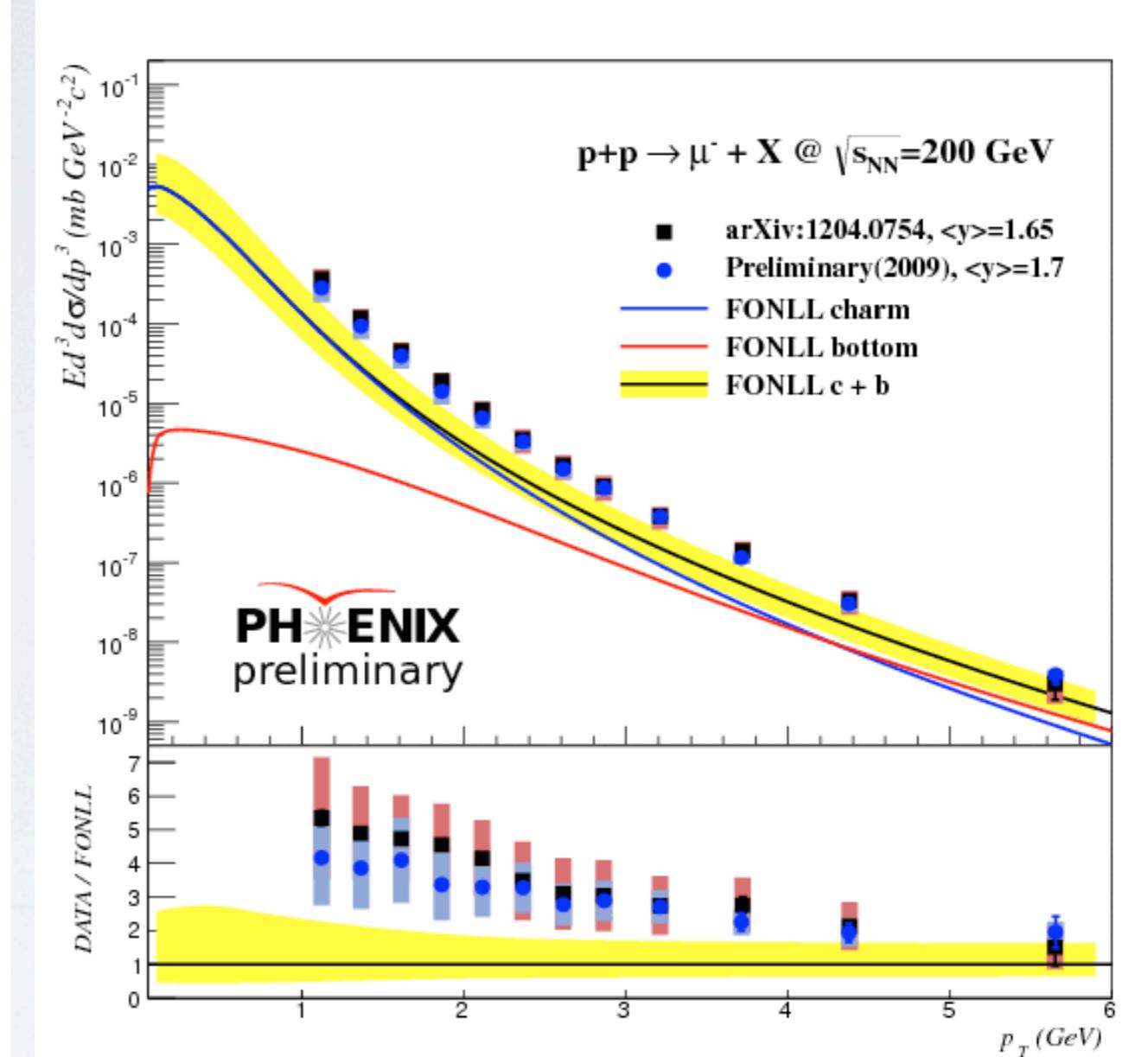
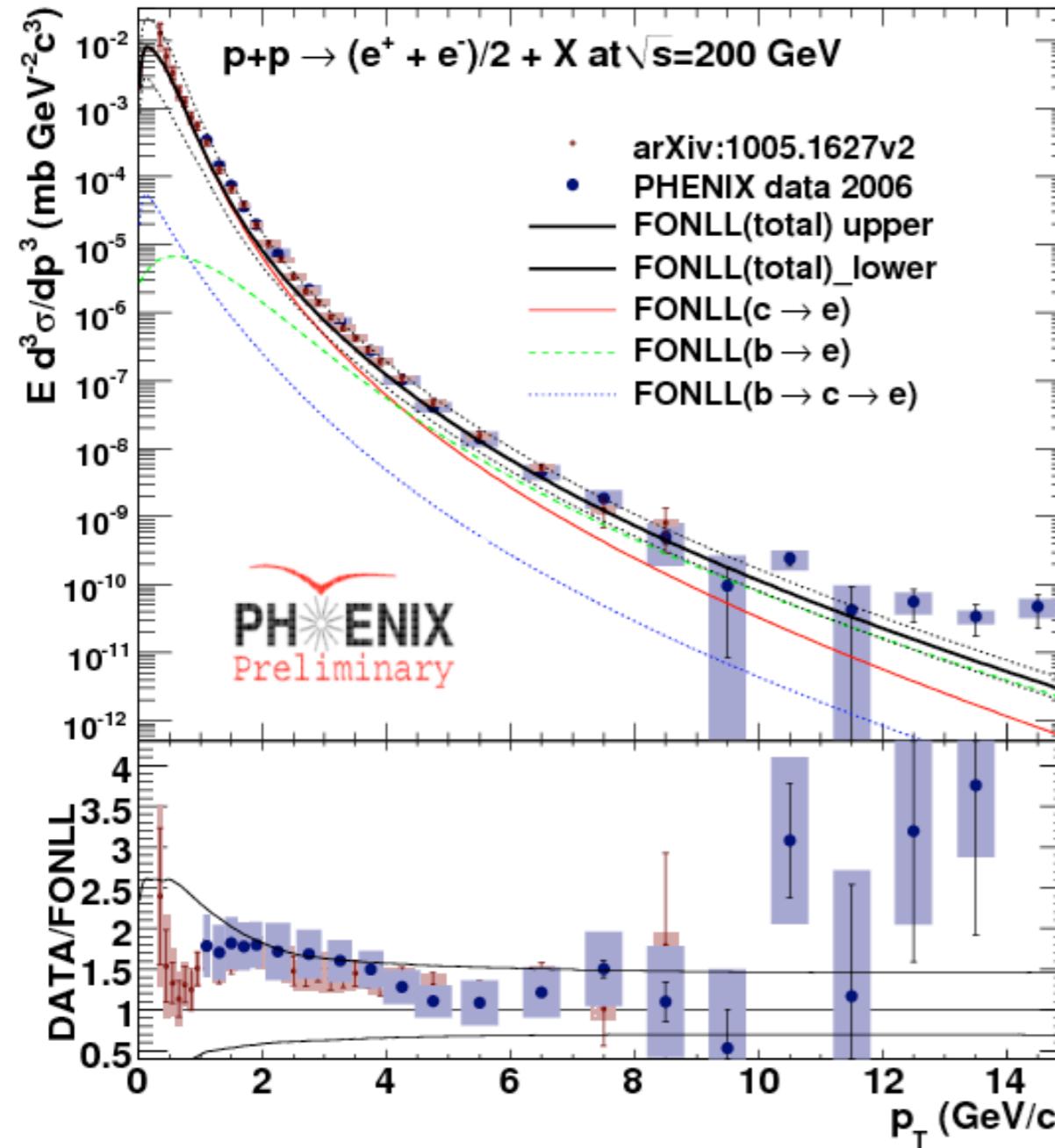
- kinematic range
  - $1.2 < |\eta| < 2.2$  at forward
  - $\Delta\varphi = 2\pi$
  - $\sim 10\lambda$  absorber to reject hadrons
  - Muon Tracker for momentum
  - Muon identifier for hadron/muon separation



- Main background sources are **decay muons** from light hadrons and **punch-through hadrons**.
- Full data-driven MC simulation of hadron cocktail ( $\pi, K, p$ )
  - Tune to data by using z-vertex dependence of decay muons at MuID Gap 4 and yields of stopped hadrons at MuID Gap 2 and 3

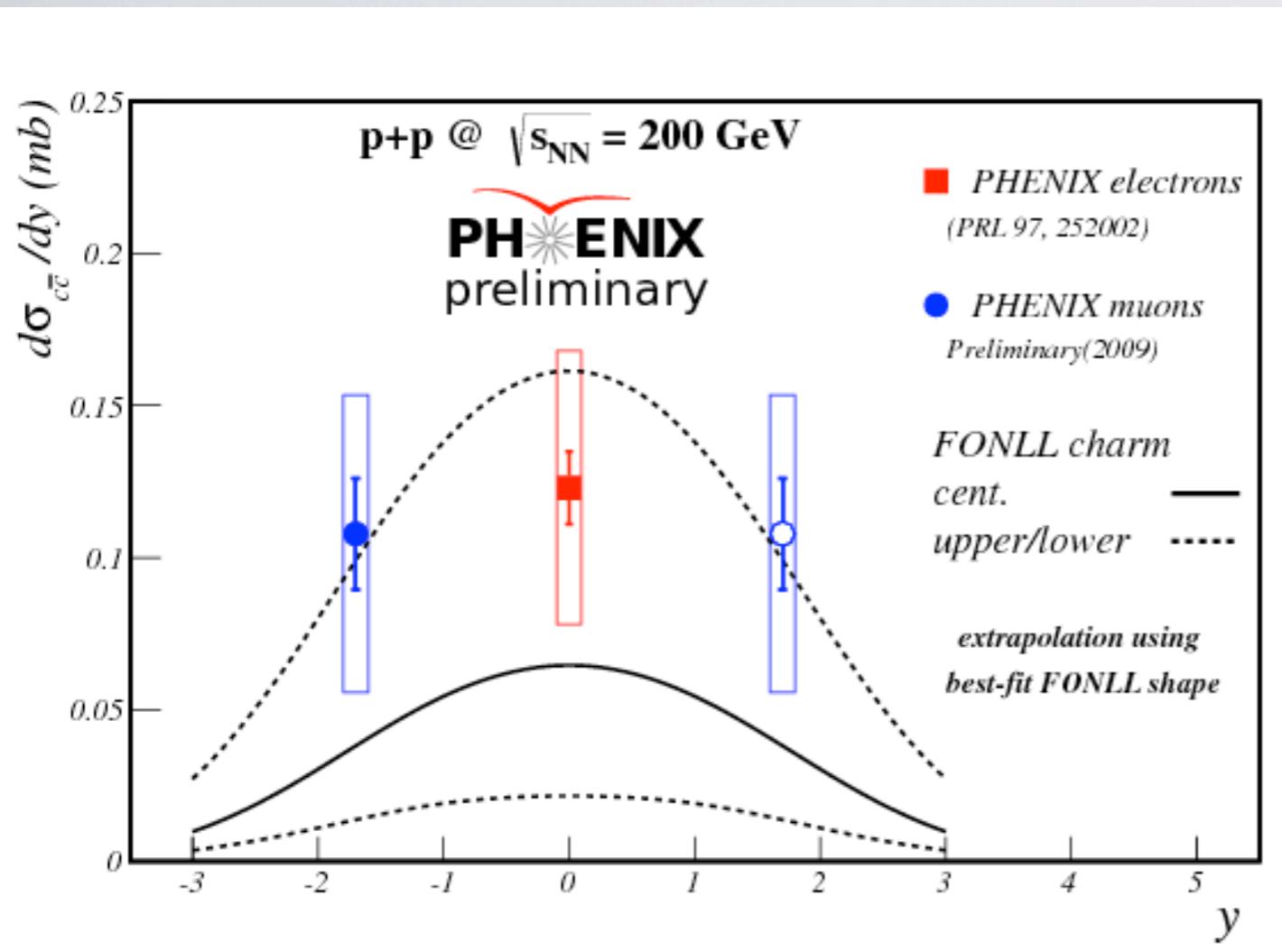
# Heavy flavor in p+p collisions

## mid-rapidity      forward rapidity



- Extend kinematic range and reduce uncertainties with enhanced statistics and improved analysis techniques

# Integrated charm cross section



$$\frac{d\sigma_{c\bar{c}}}{dy} \Big|_{y=0} = 0.123 \pm 0.012(\text{stat.}) \pm 0.045(\text{sys.}) \text{ mb}$$

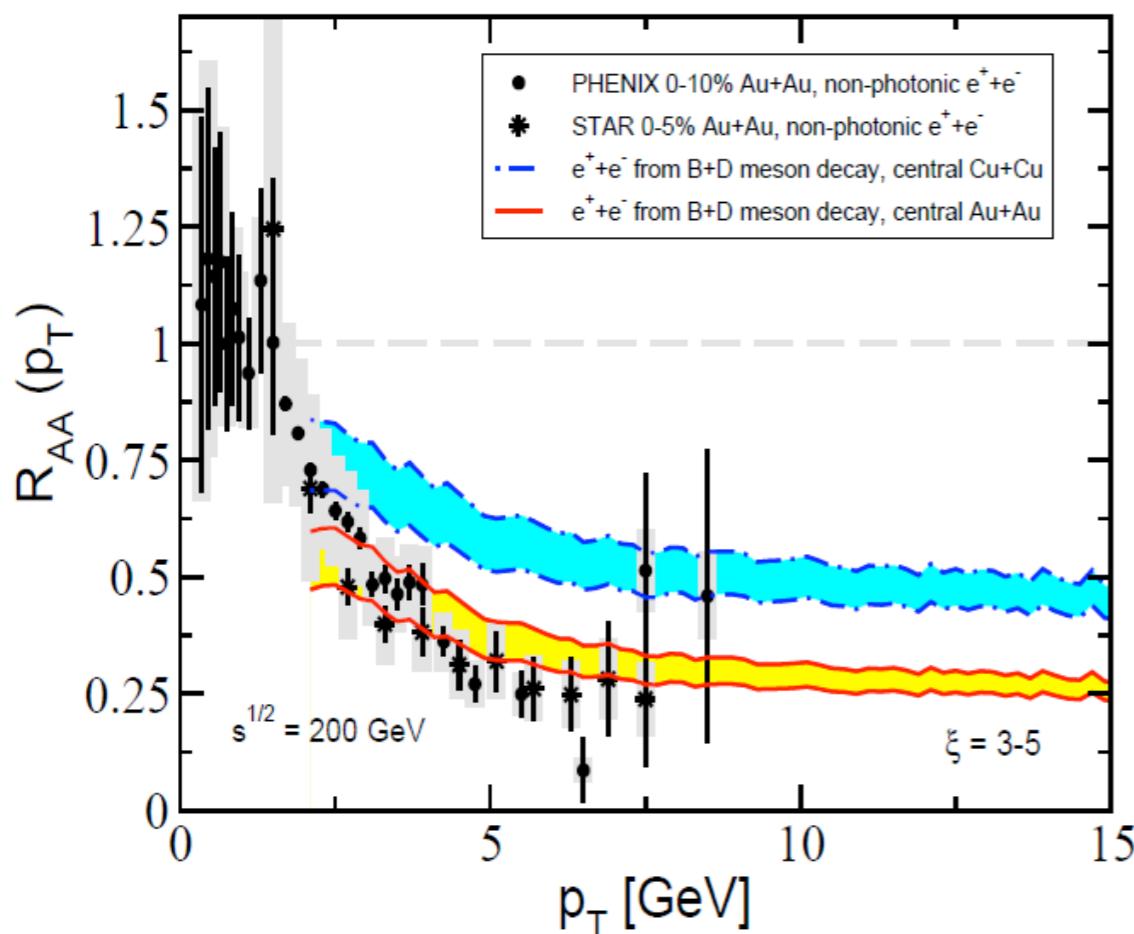
$$\frac{d\sigma_{c\bar{c}}}{dy} \Big|_{y=1.7} = 0.108 \pm 0.018(\text{stat.})^{+0.046}_{-0.052}(\text{sys.}) \text{ mb}$$

- Charm cross section by extrapolating to  $p_T=0$  using FONLL shape
  - consistent with FONLL upper limit

# How to quantify medium effects

- Nuclear modification factor
  - $R_{AA} = 1$  : No overall modification
  - $R_{AA} < 1$  : Suppression
  - $R_{AA} > 1$  : Enhancement

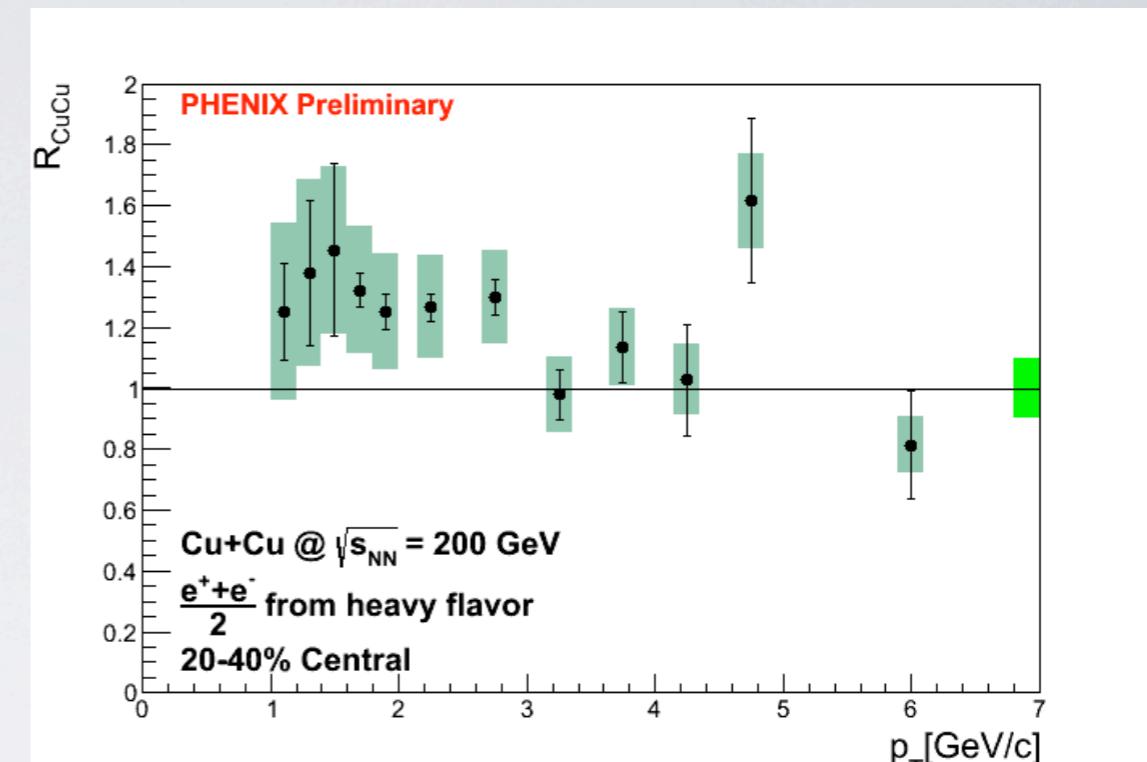
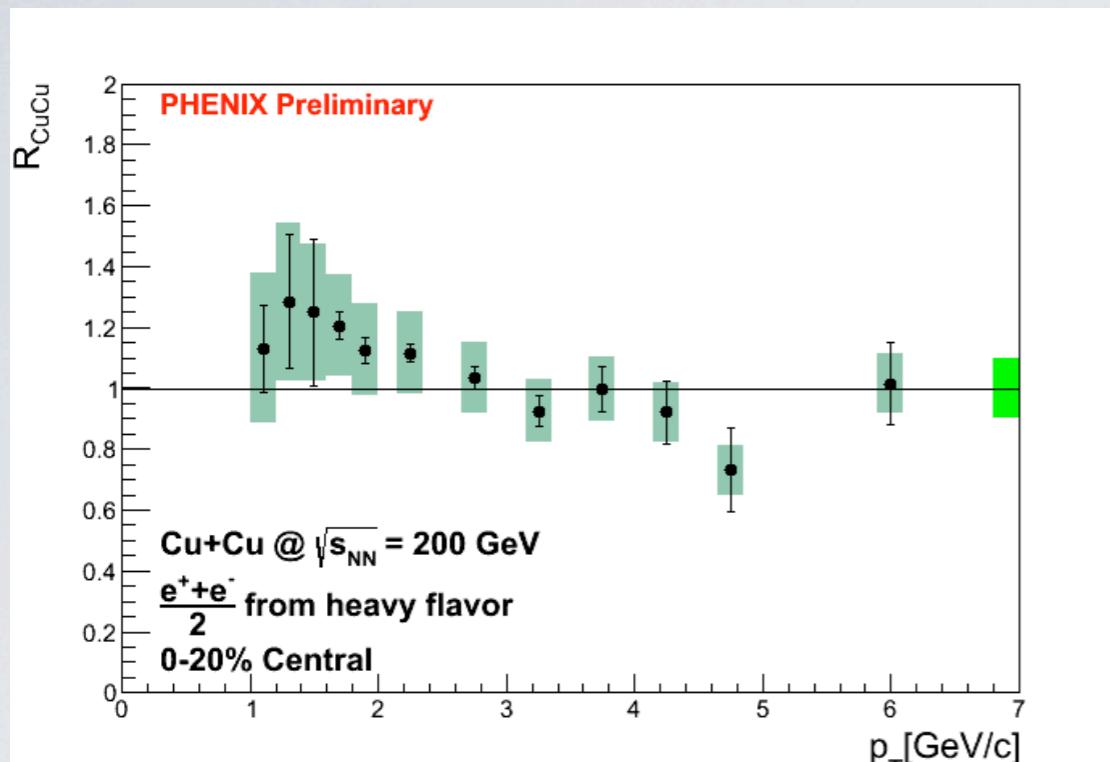
$$R_{AA} = \frac{dN_{AA}}{\langle N_{coll} \rangle \times dN_{pp}}$$



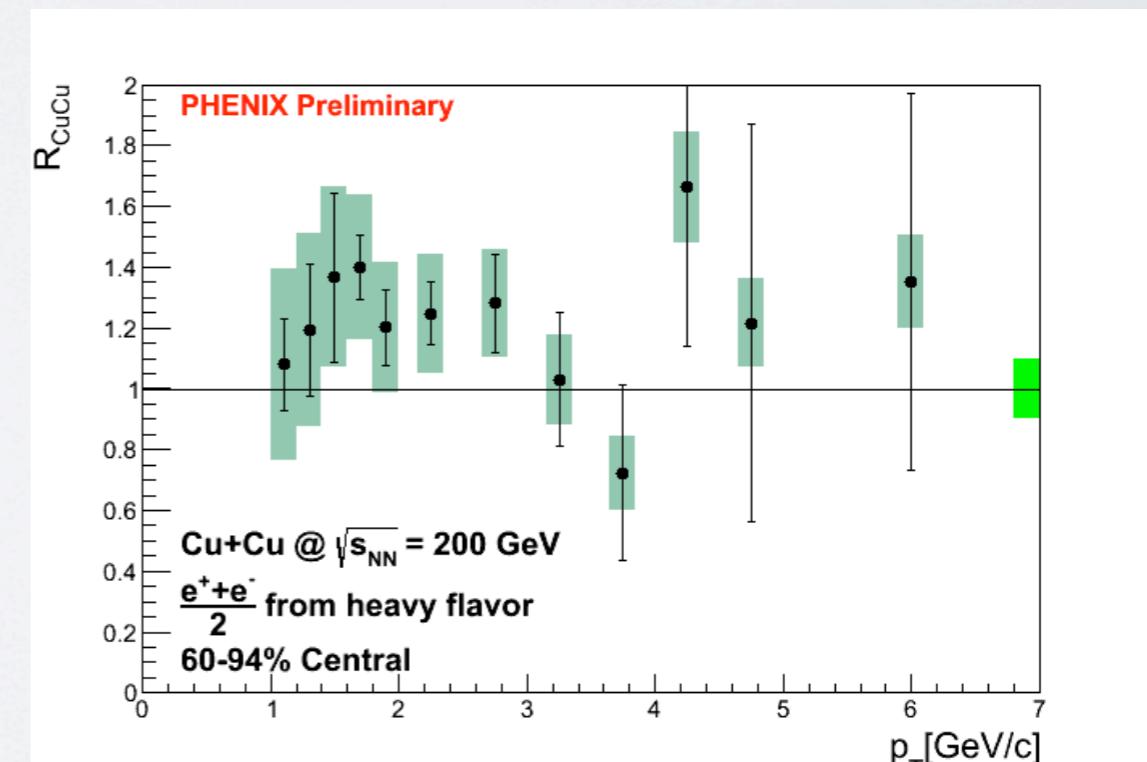
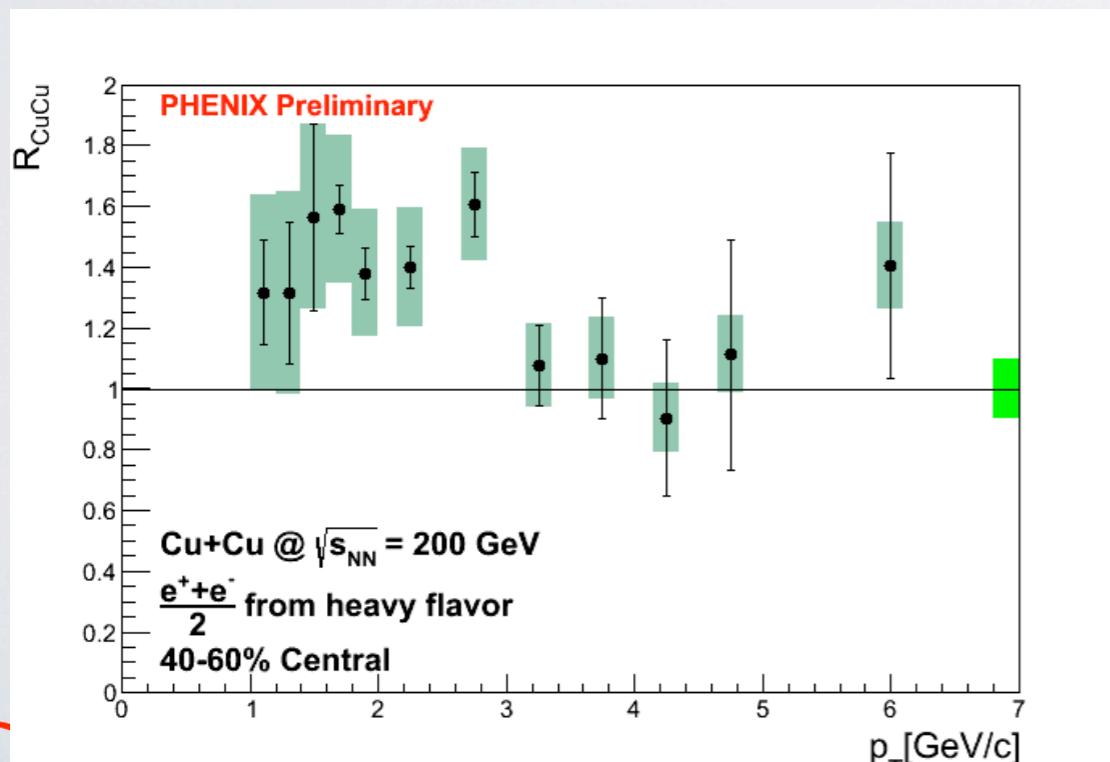
Phys. Rev. C 80, 054902 (2009)

- Theoretical model (Sharma, Vitev and Zhang)
  - includes partonic energy loss and collisional dissociation
  - CNM effects such as shadowing, Cronin effect and initial energy loss
- Comparison to data will be shown
  - Cu+Cu at mid and forward
  - d+Au at forward

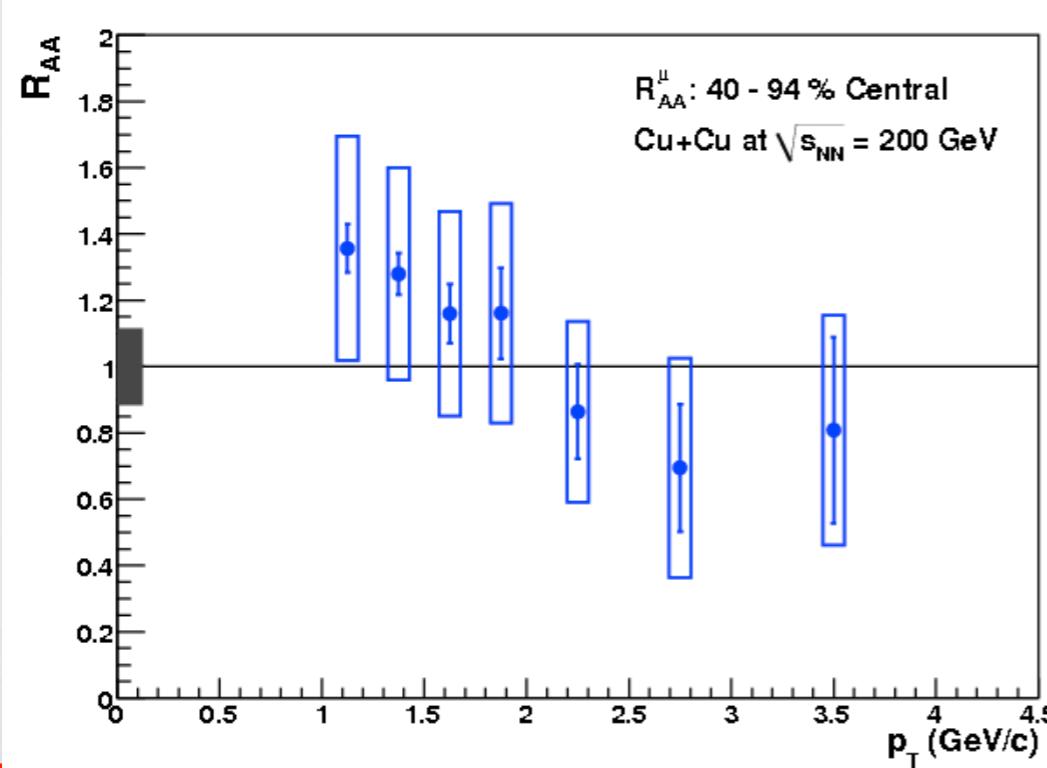
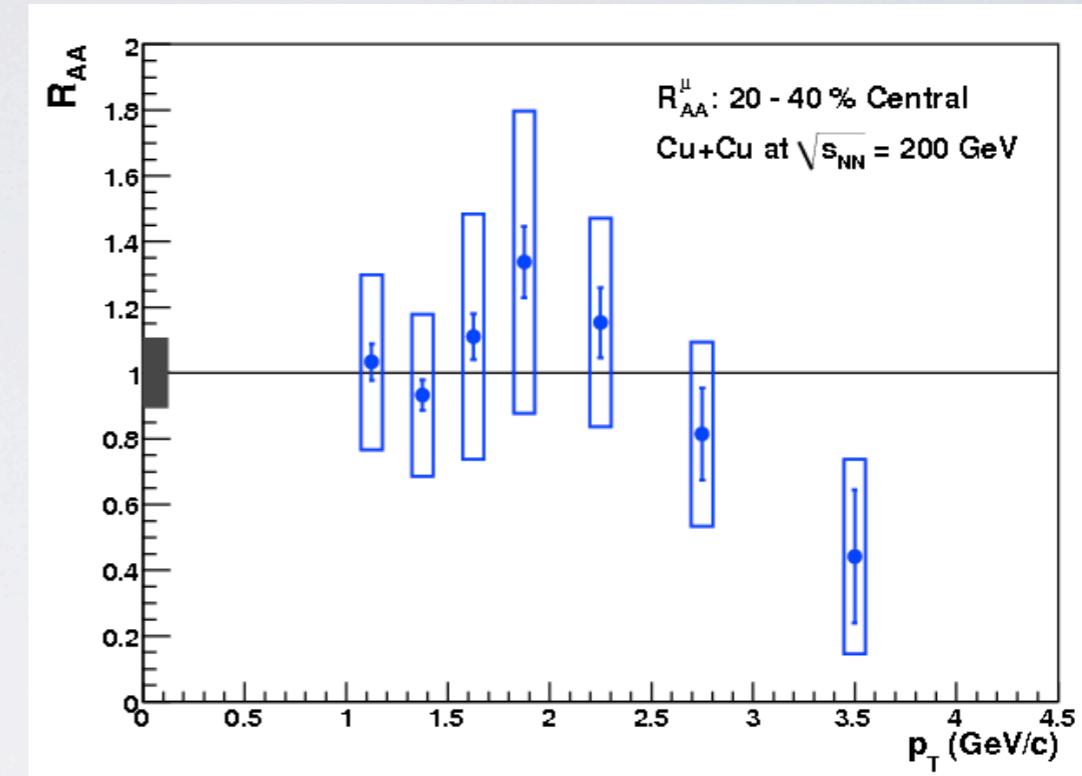
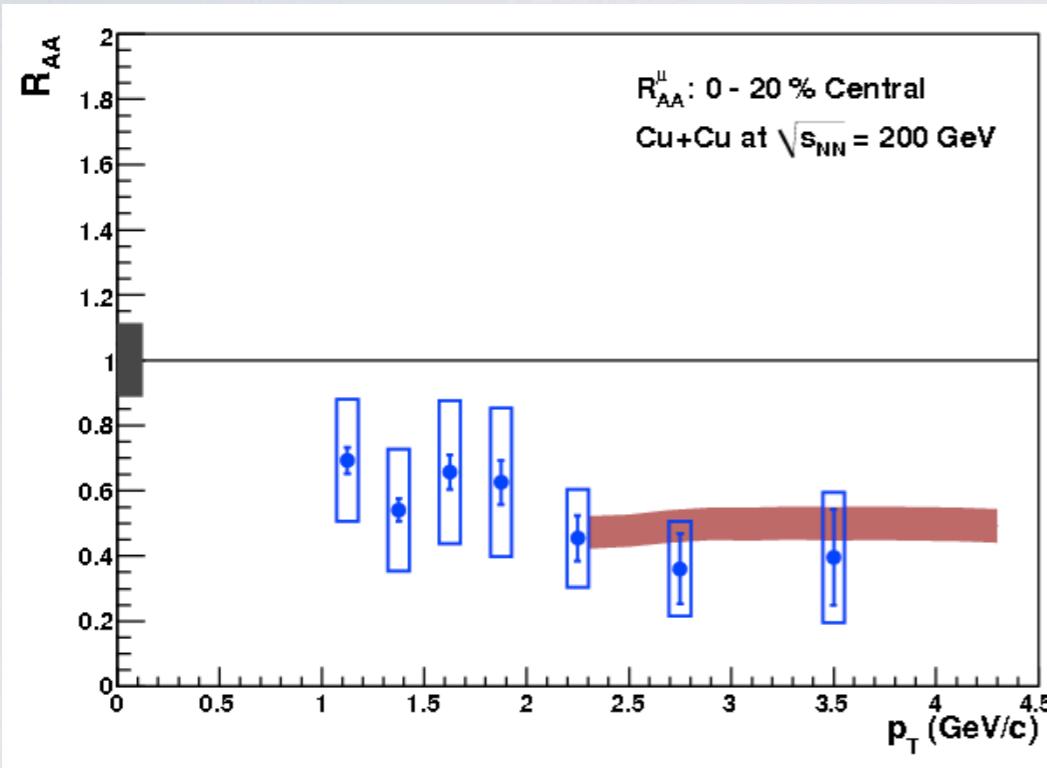
# Heavy flavor electrons $R_{AA}$ at mid-rapidity



## Enhancement in the mid-central and mid-peripheral collisions

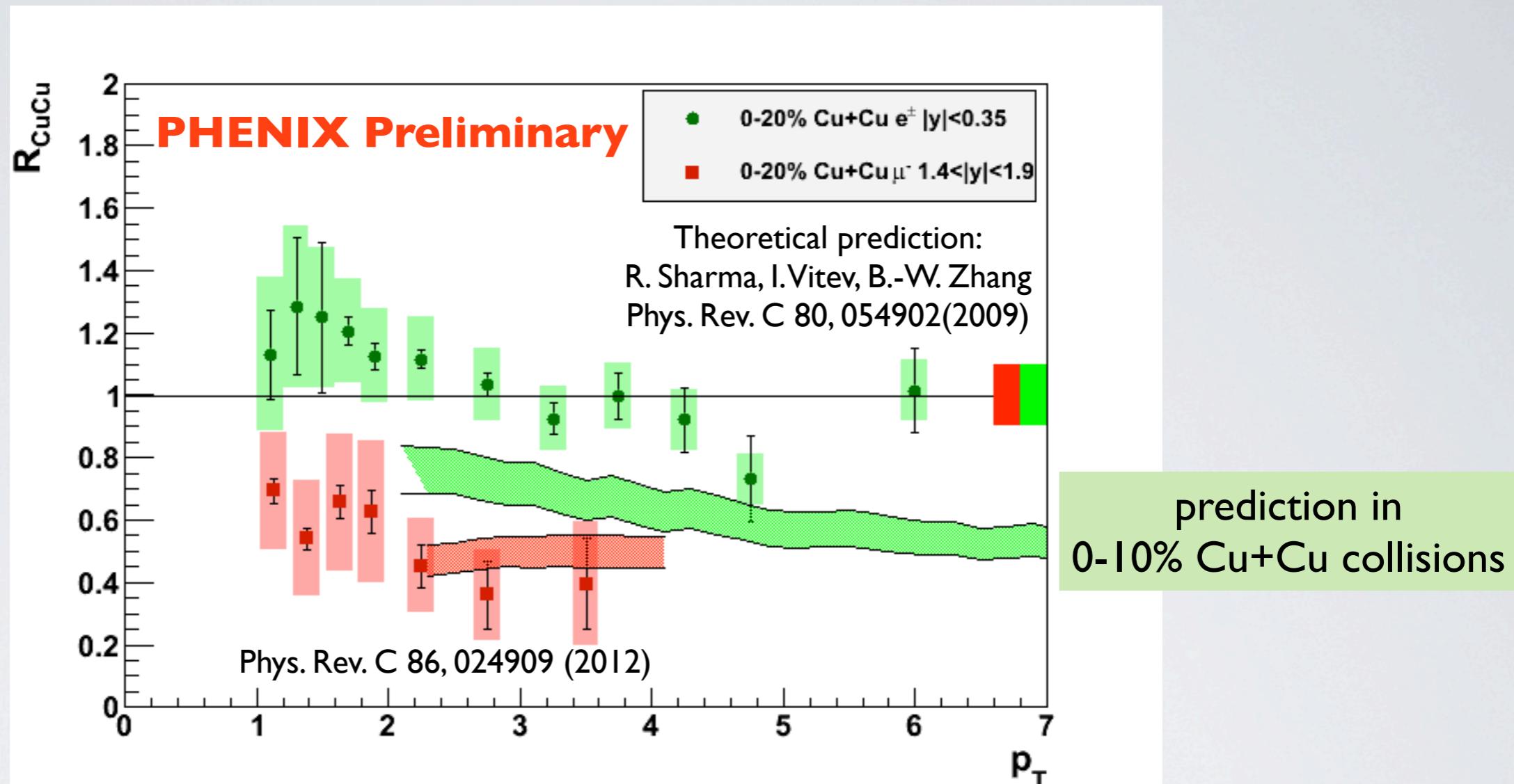


# Heavy flavor muons $R_{AA}$ at forward-rapidity



**suppression!**  
in the most central collisions  
Phys. Rev. C 86, 024909 (2012)

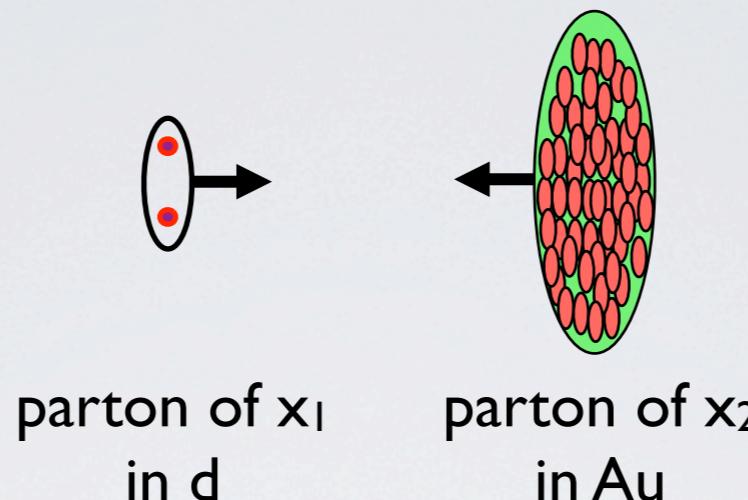
# Heavy flavor in Cu+Cu compared to theory



- The most central (0-20%) Cu+Cu collisions
  - well describe suppression at forward rapidity with additional CNM effects (shadowing, initial energy loss)

# Cold nuclear matter effects in d+Au collisions

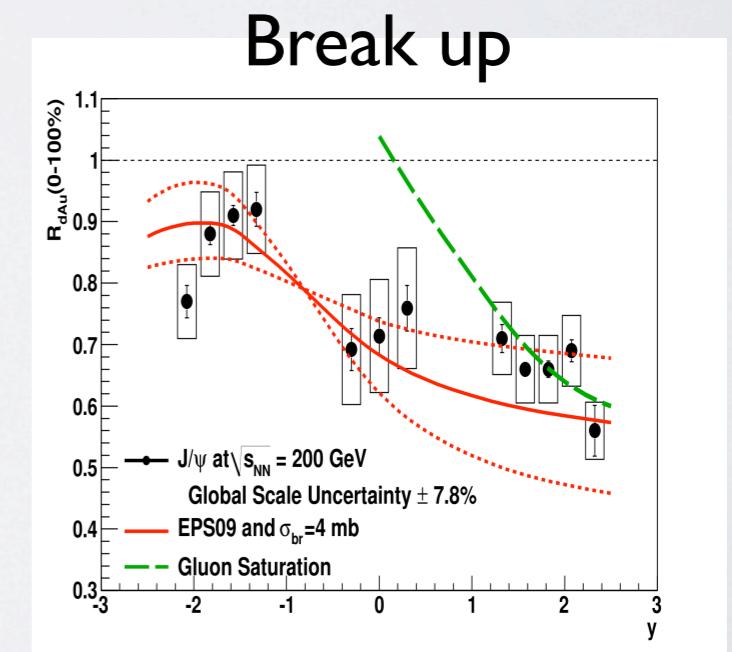
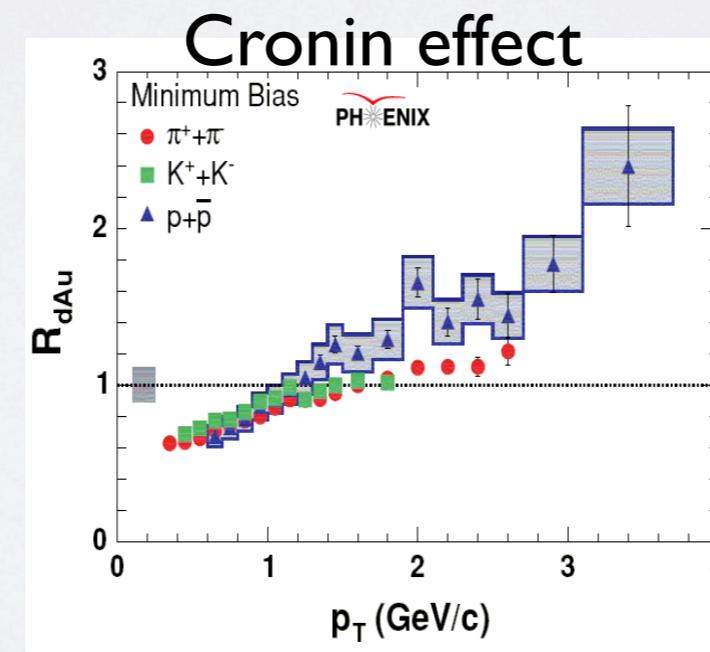
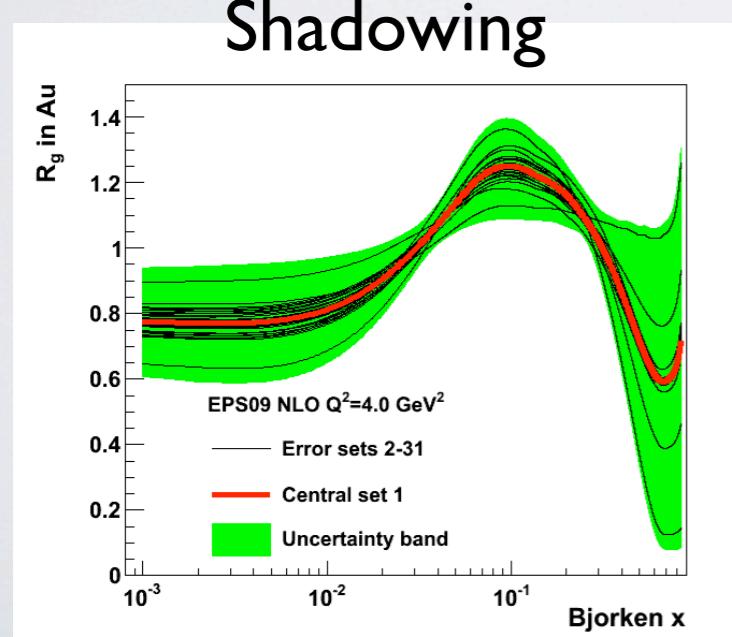
Backward rapidity  
 \*Au-going side  
 $*x_1 < x_2$



Forward rapidity  
 \*d-going side  
 $*x_1 > x_2$

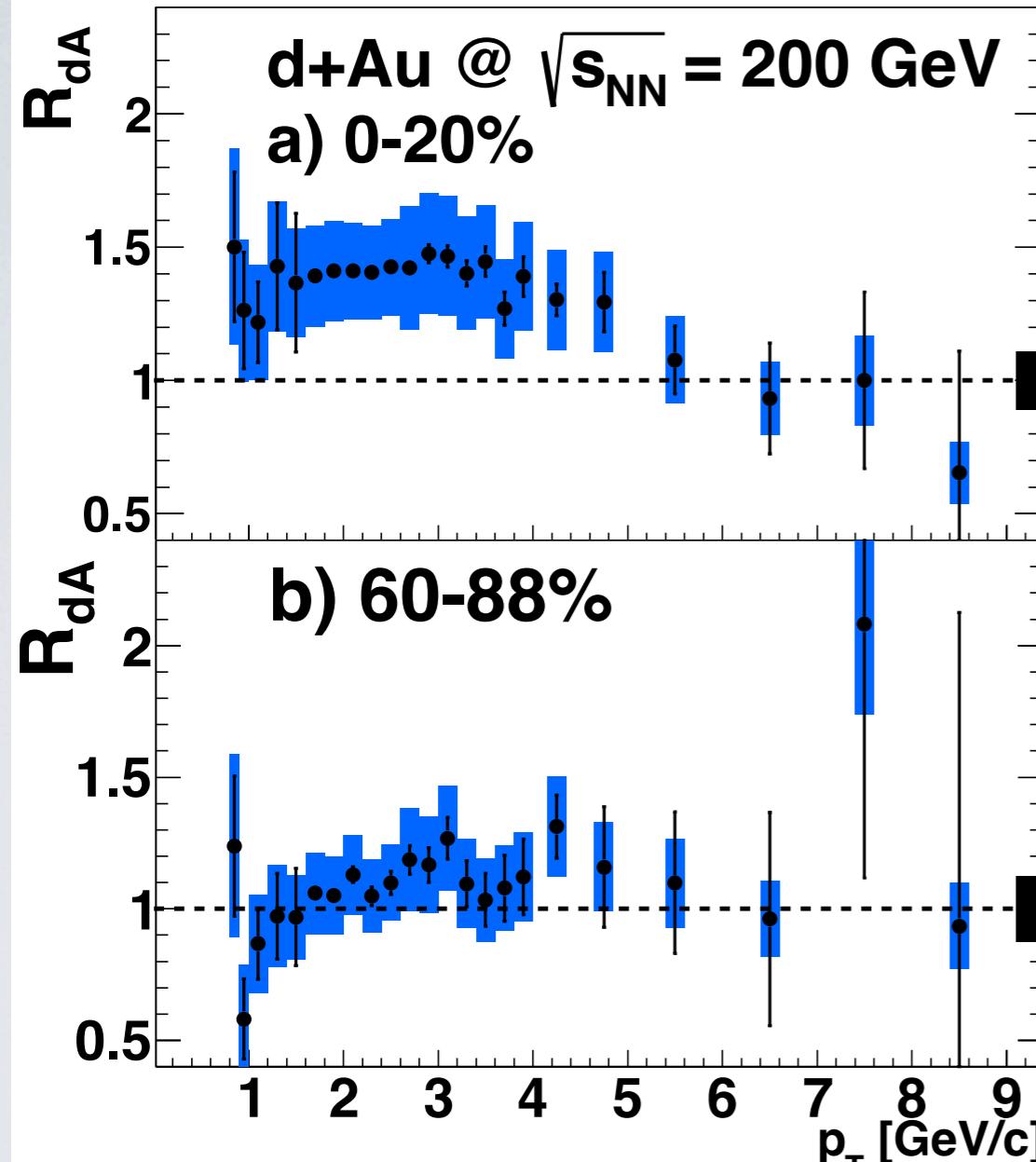
$$x_2 = \frac{Q}{\sqrt{s_{NN}}} e^{-y}$$

- d+Au collision as controlled experiment
  - In heavy ion collision, CNM & HNM effects are mixed
  - baseline measurements without hot nuclear medium in heavy ion collisions



# Heavy flavor electrons $R_{dA}$

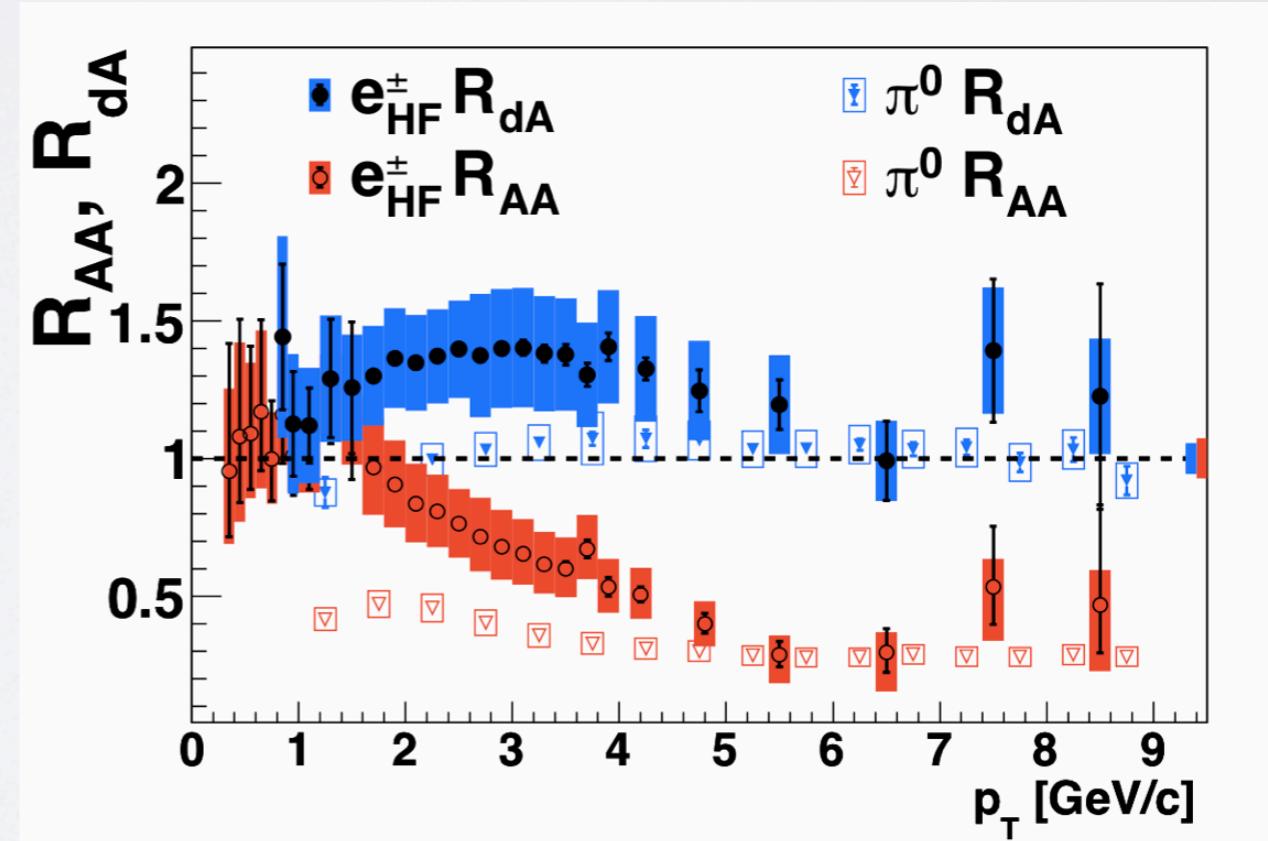
mid-rapidity



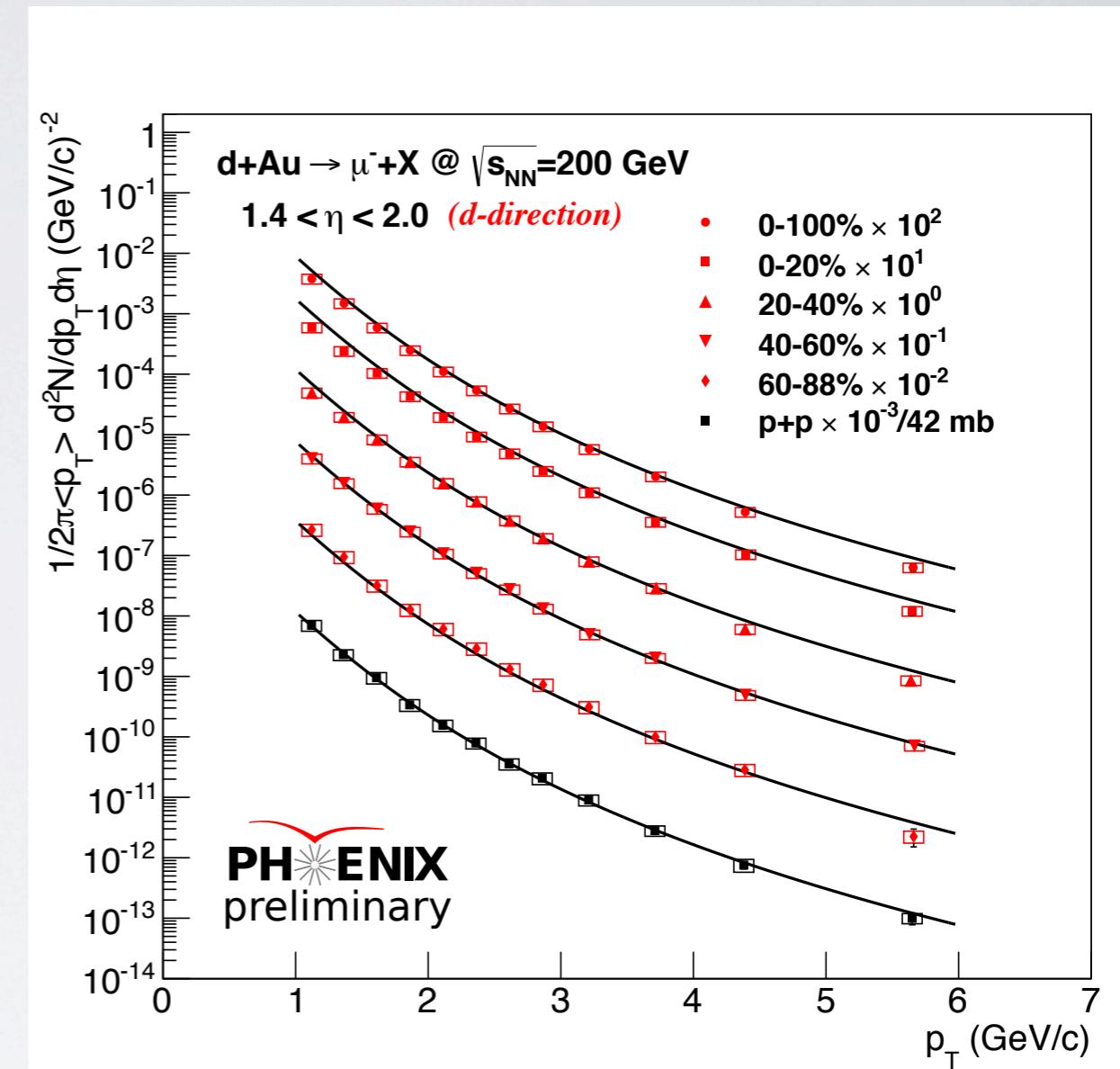
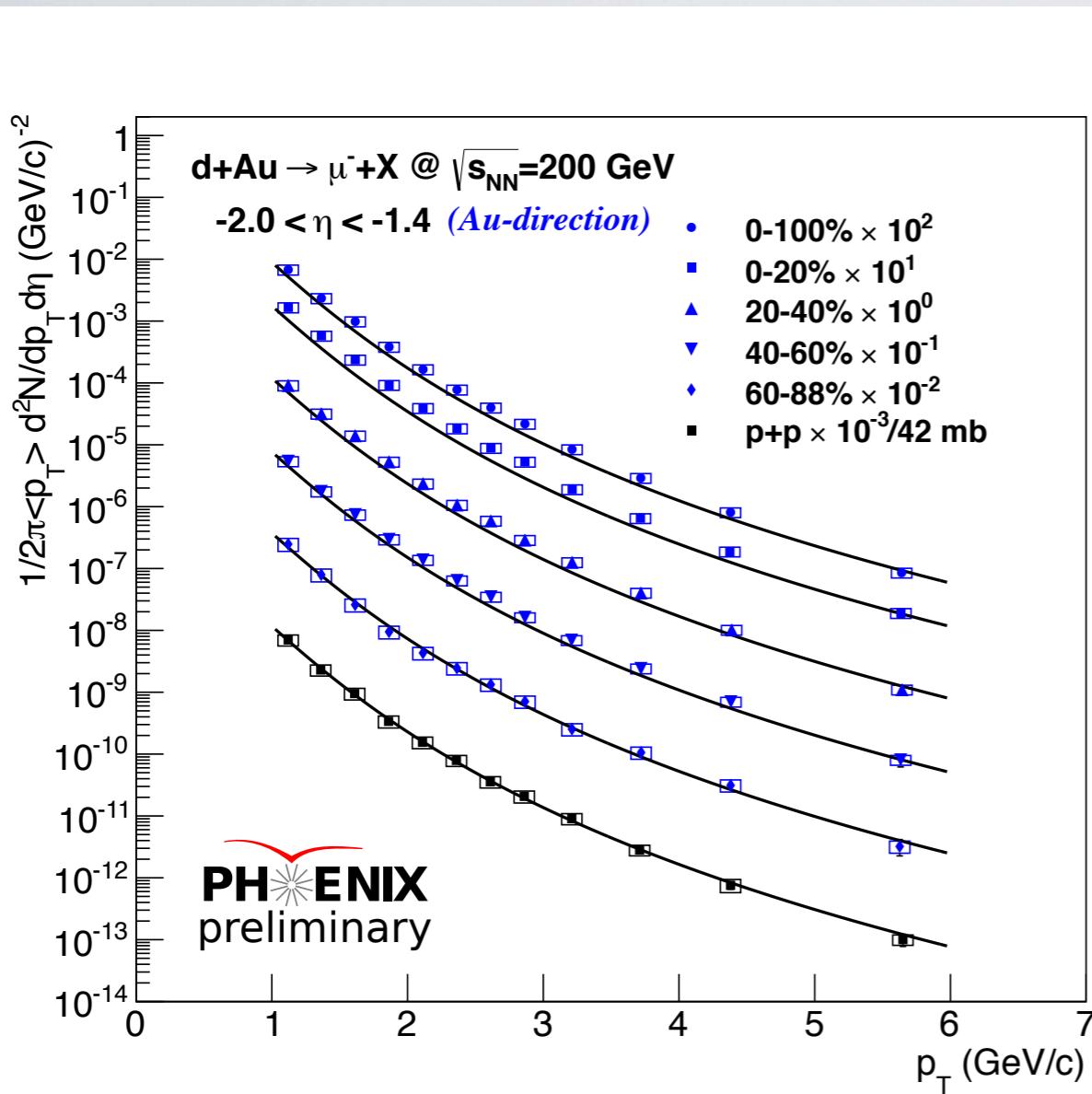
Phys. Rev. Lett. 109, 242301 (2012)

- Large enhancement in the central collision
  - mass ordering Cronin effect
- $R_{dA} \sim 1$  in the peripheral collisions

0-20% centrality

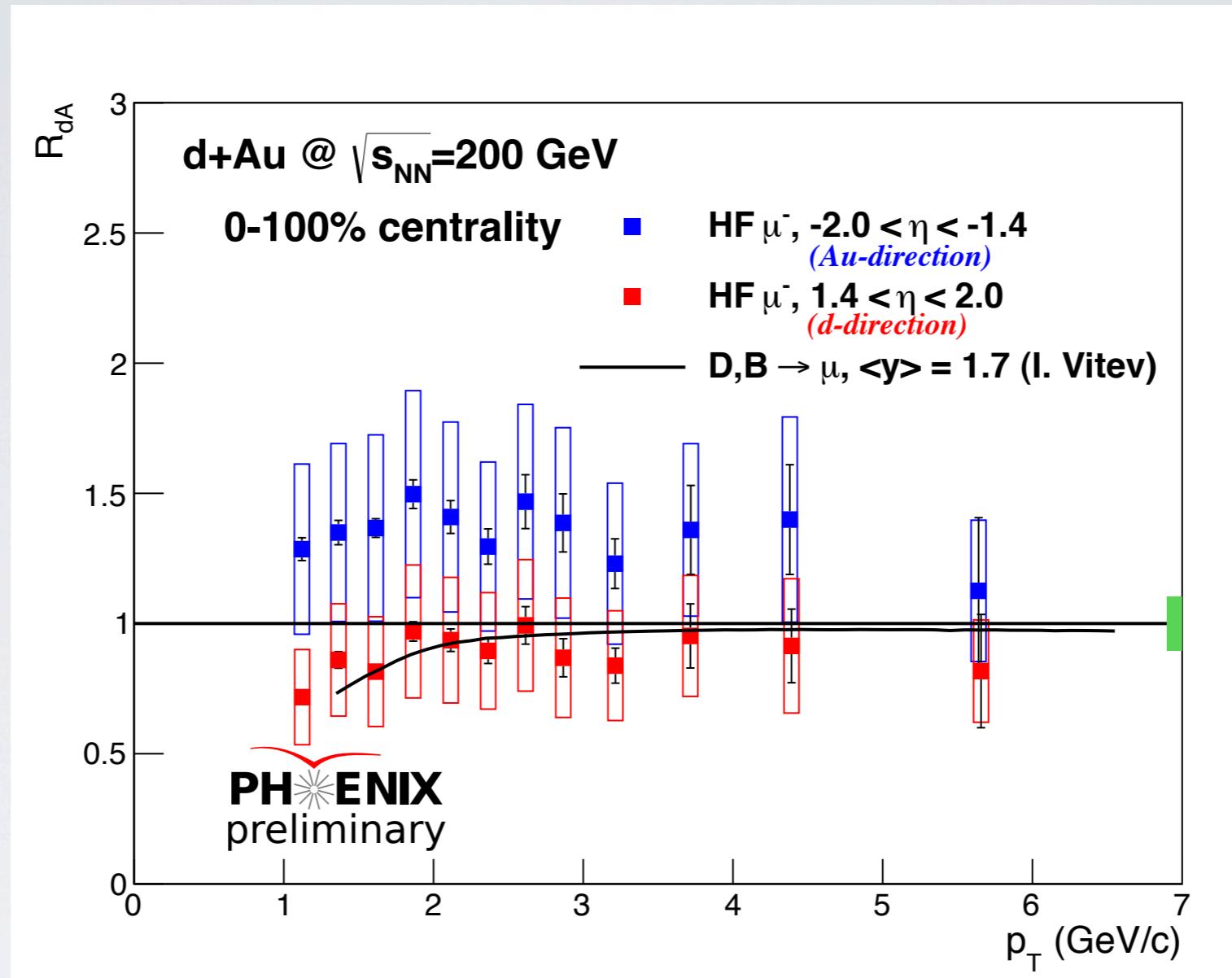


# Heavy flavor muons in d+Au



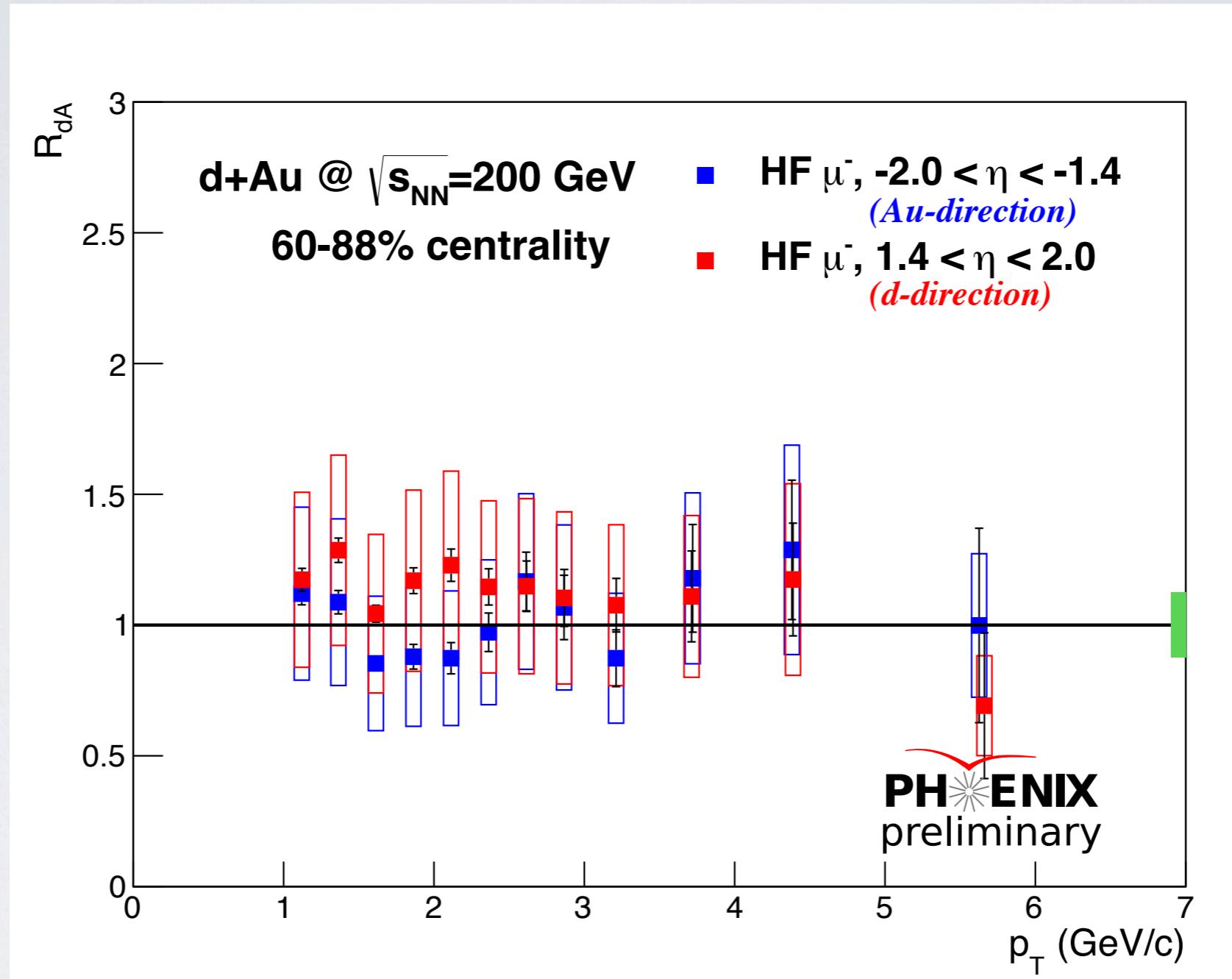
- HF single muons  $p_T$  spectra at **backward(Au-direction, left)** and at **forward(d-direction, right)** in  $d+Au$  collisions
  - lines are  $T_{AB}$  scaled fit function of spectra in p+p collisions

# Heavy flavor muons $R_{dA}$ , Min Bias



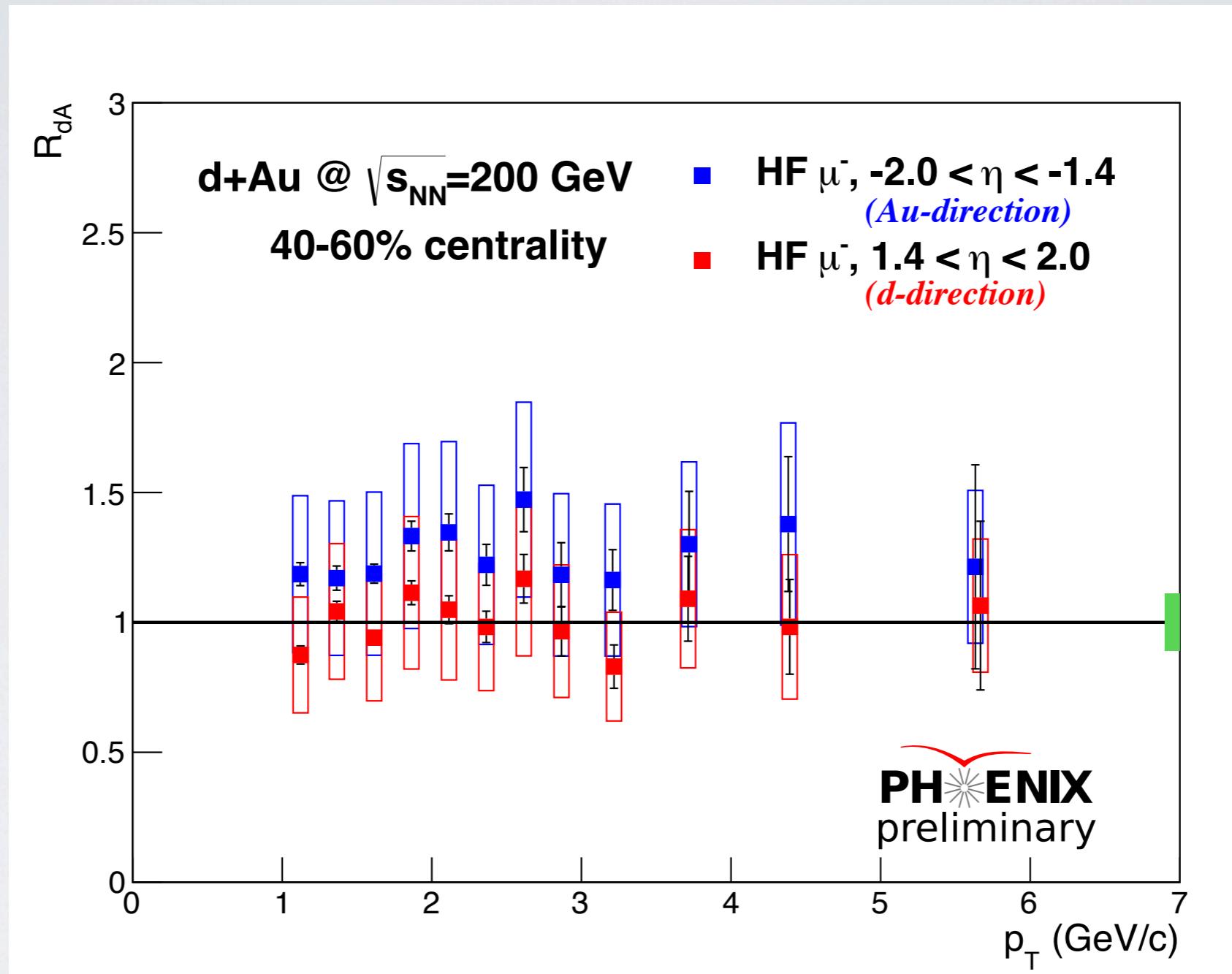
- good agreement with the prediction from I.Vitev
  - muon production from D and B meson at  $\langle y \rangle = 1.7$
  - considering shadowing, Cronin effect and initial parton energy loss

# Heavy flavor single muons $R_{dA}$ , 60 - 88%

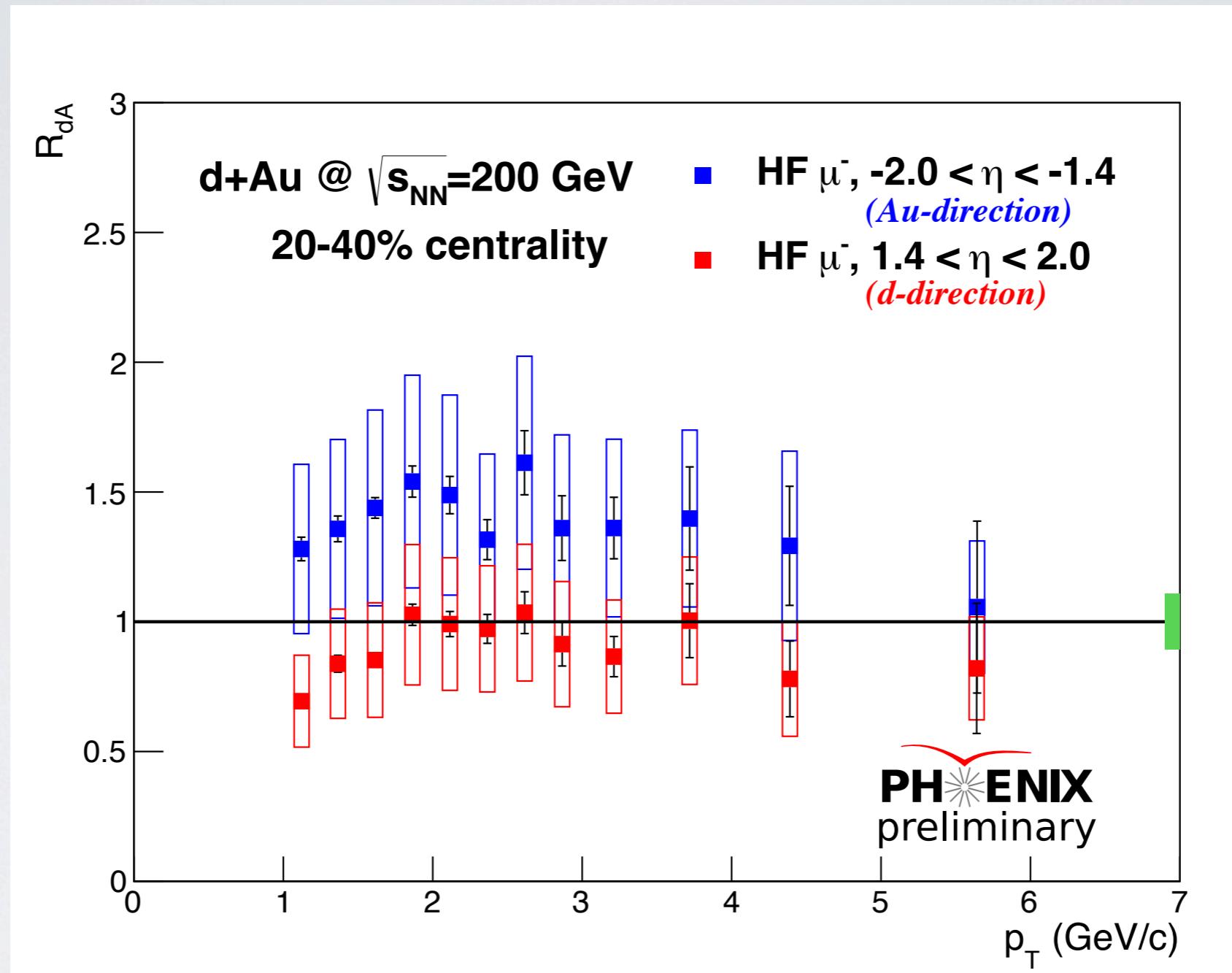


Consistent between forward and backward  
in the most peripheral d+Au collisions

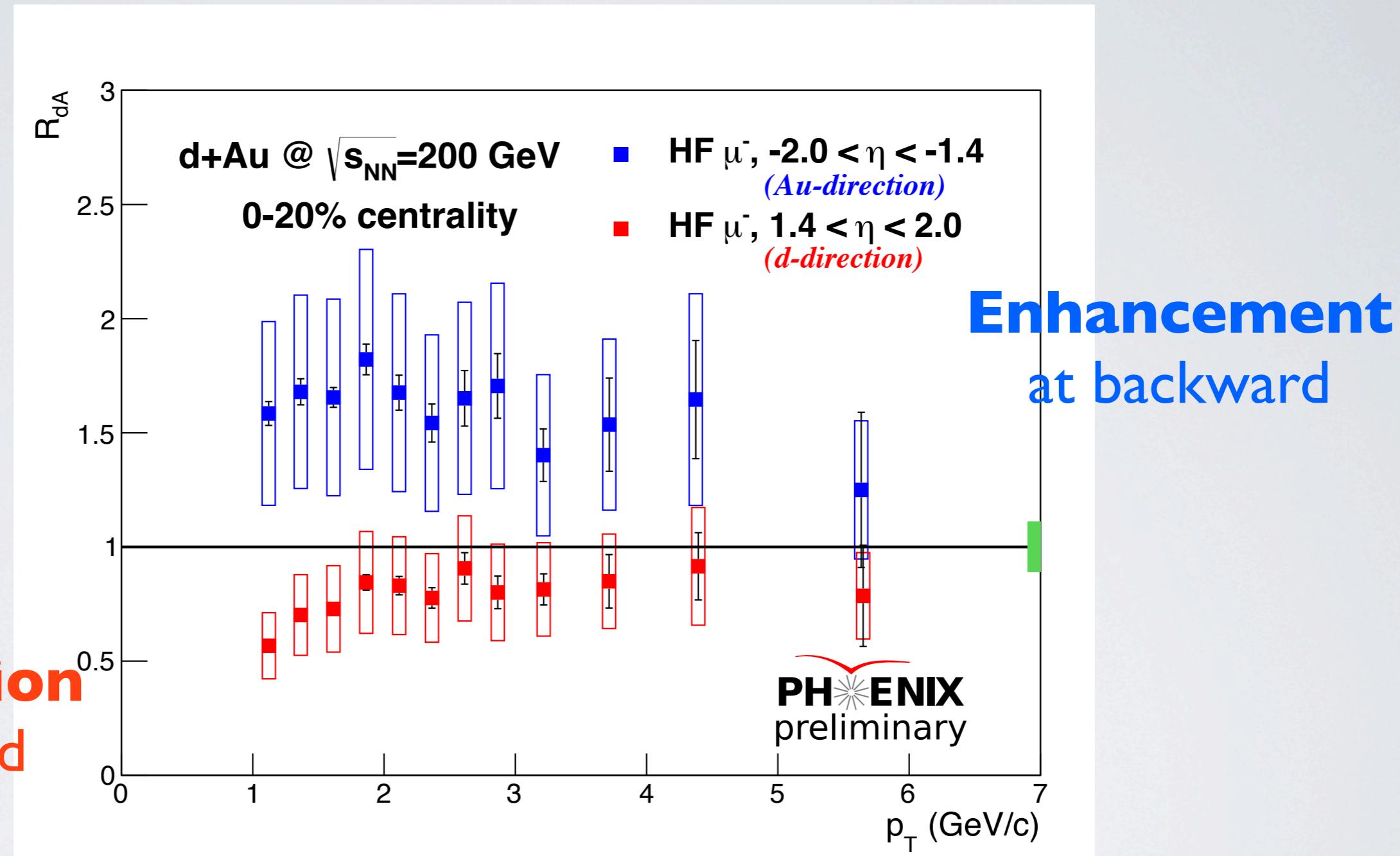
# Heavy flavor muons $R_{dA}$ , 40 - 60%



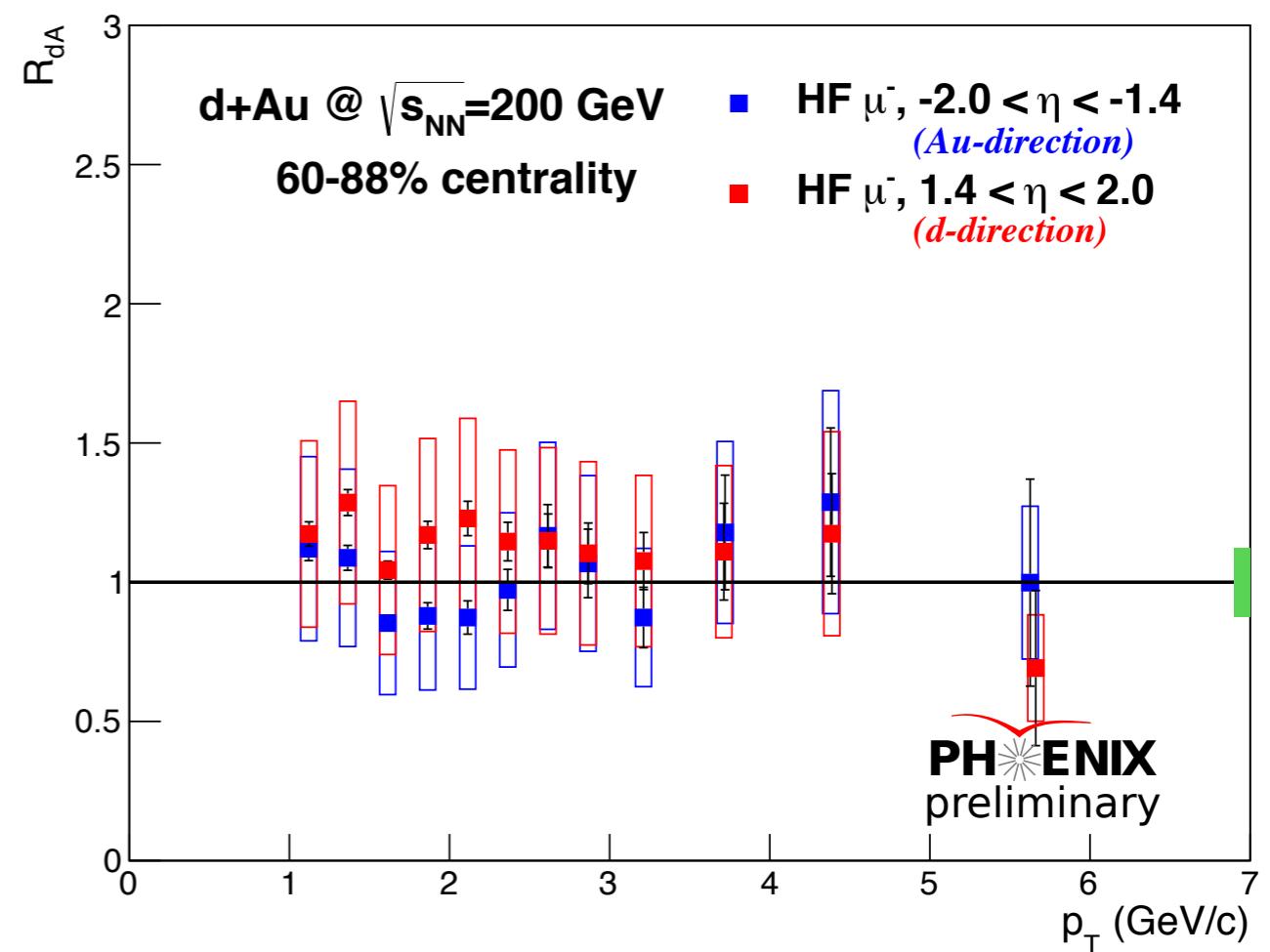
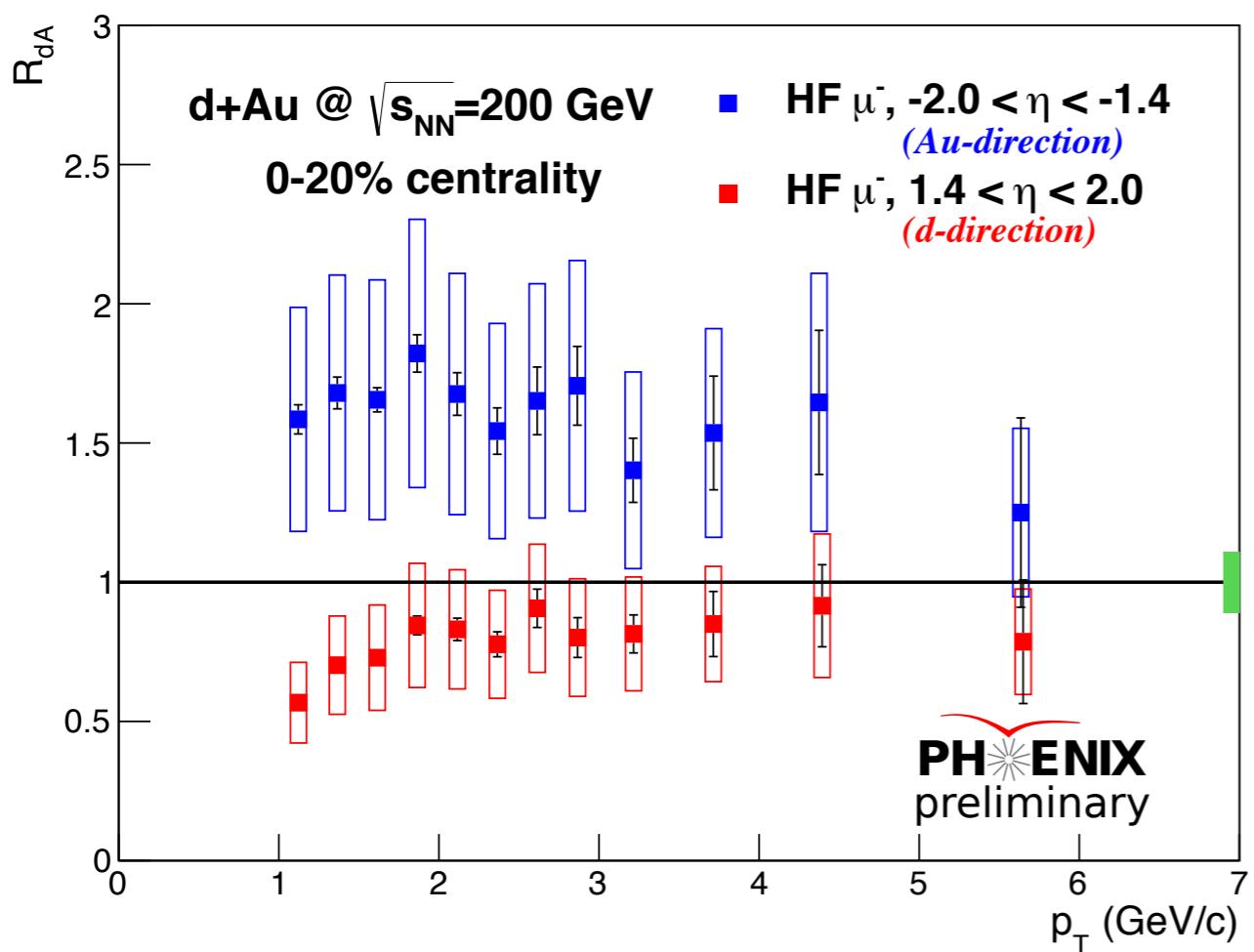
# Heavy flavor muons $R_{dA}$ , 20 - 40%



# Heavy flavor muons $R_{dA}$ , 0 - 20%



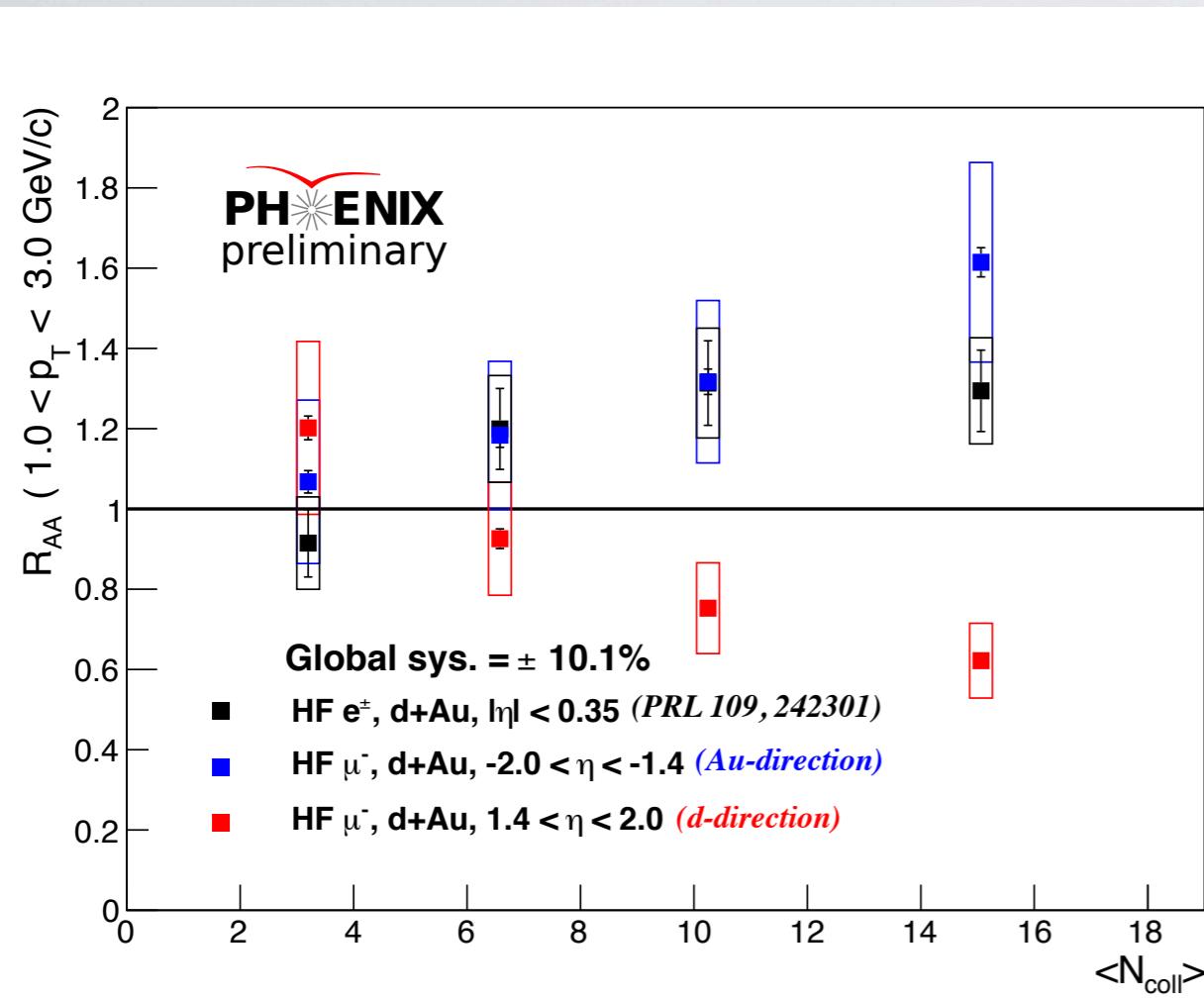
# Heavy flavor muons $R_{dA}$ , central vs. peripheral



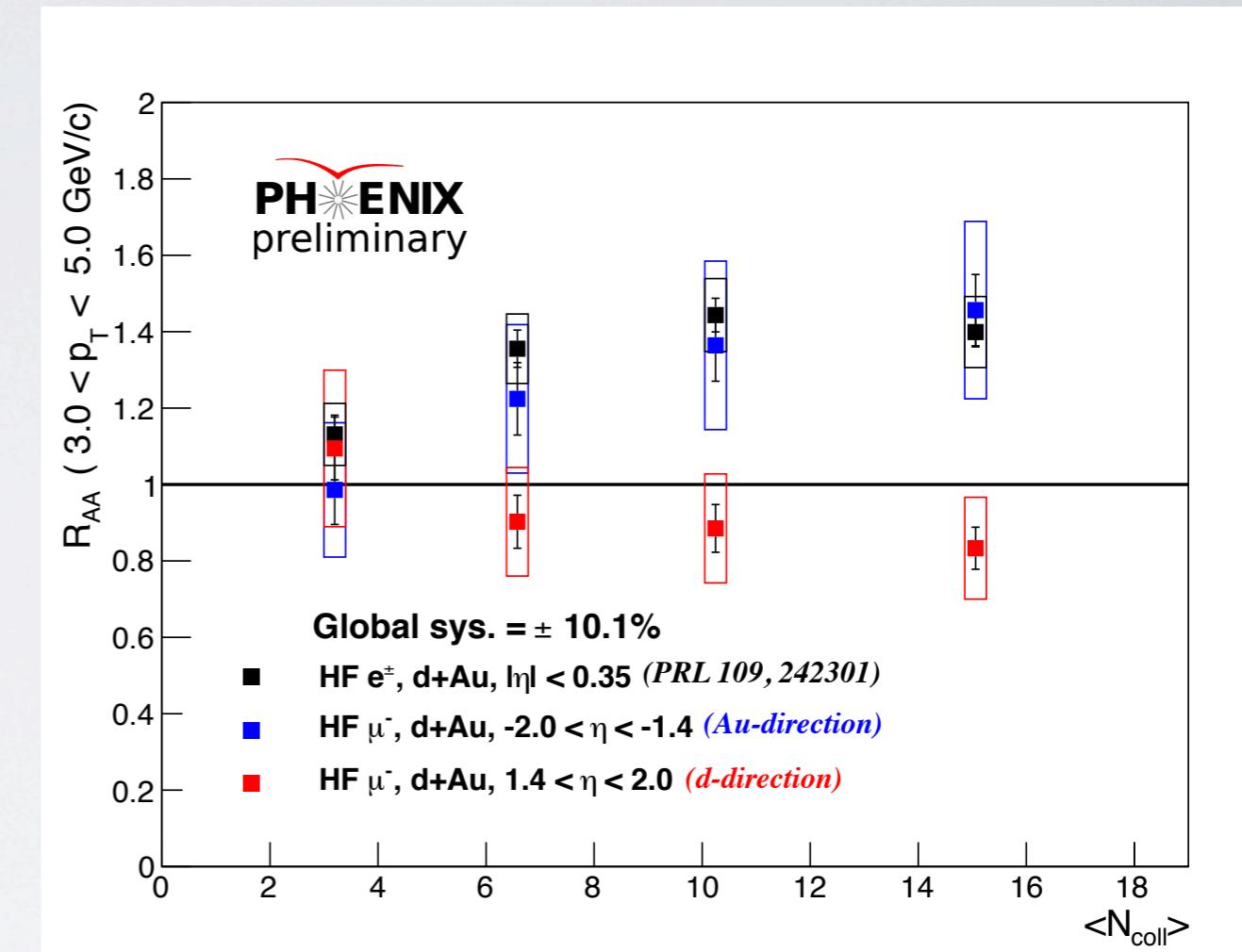
Strong CNM effects in the most central d+Au collisions!

# Heavy flavor muons $R_{dA}$ vs. $N_{coll}$

$1.0 < p_T < 3.0 \text{ GeV}/c$



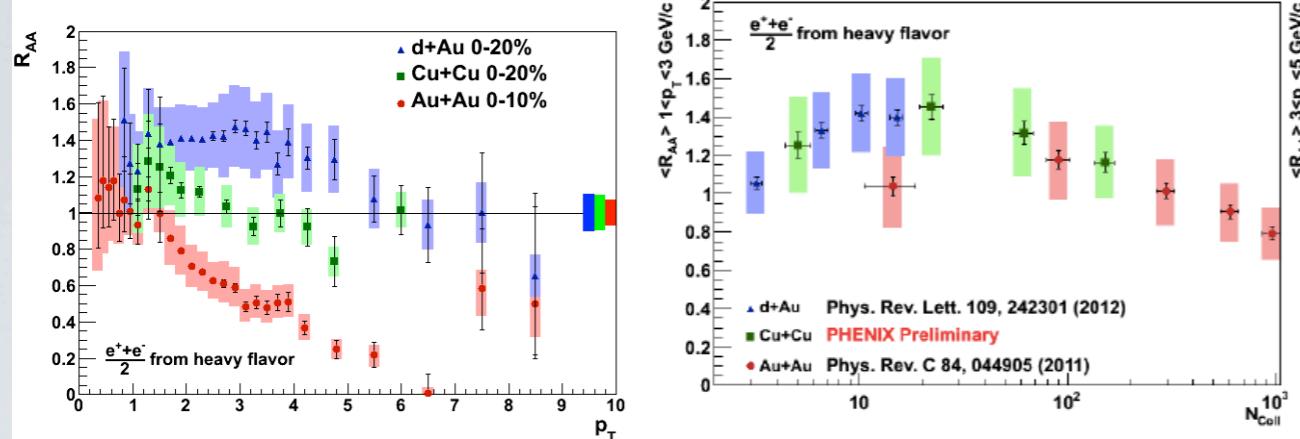
$3.0 < p_T < 5.0 \text{ GeV}/c$



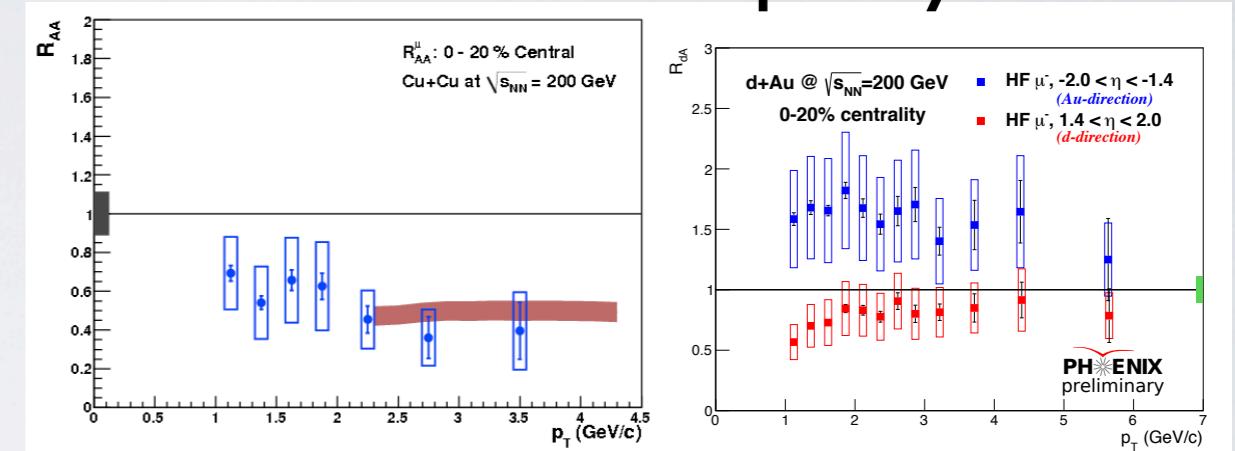
- Stronger centrality dependence at low  $p_T$  region
  - similar trends at backward and mid-rapidity
  - opposite trend at forward, more suppression as larger  $N_{coll}$

- PHENIX measured open heavy flavors in various collision system

mid-rapidity



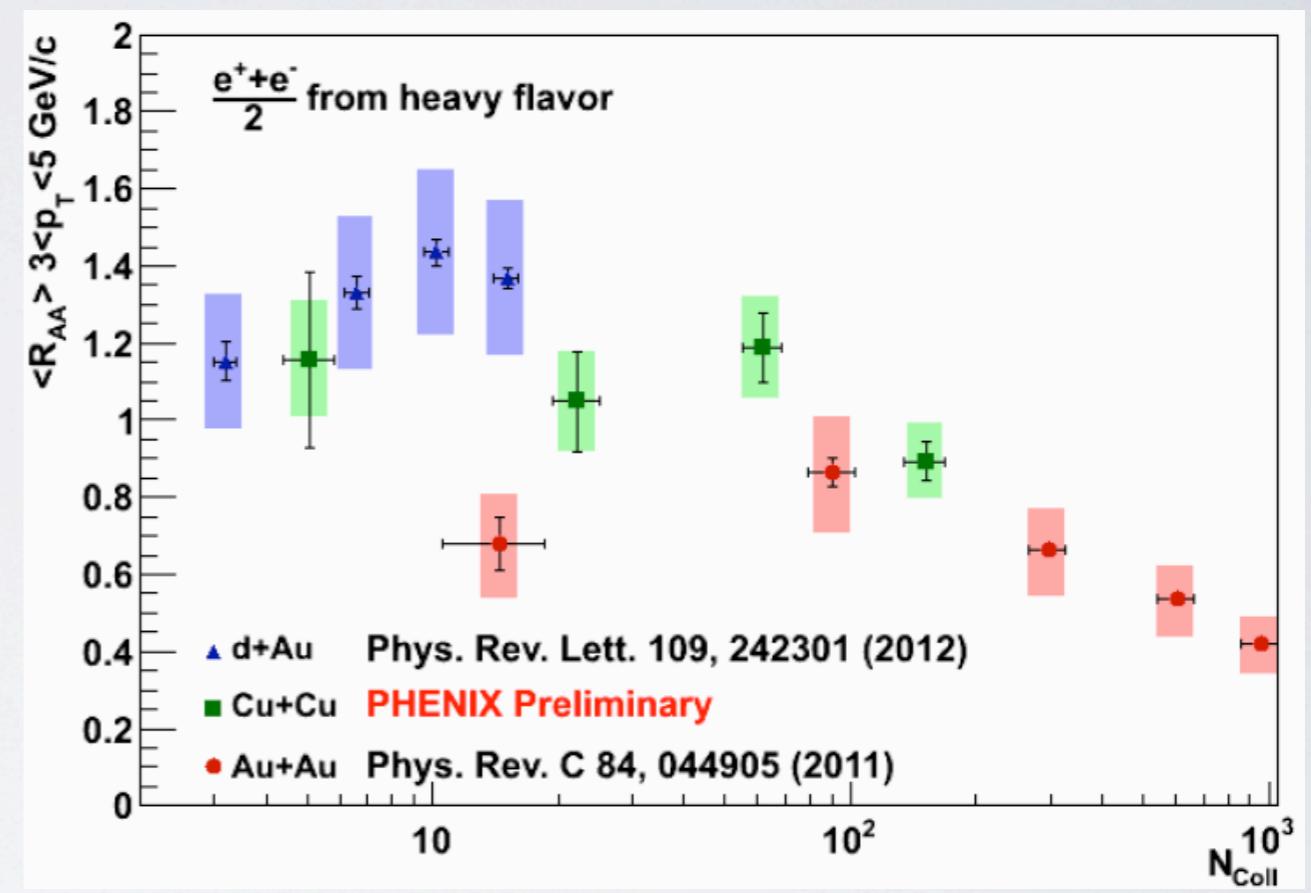
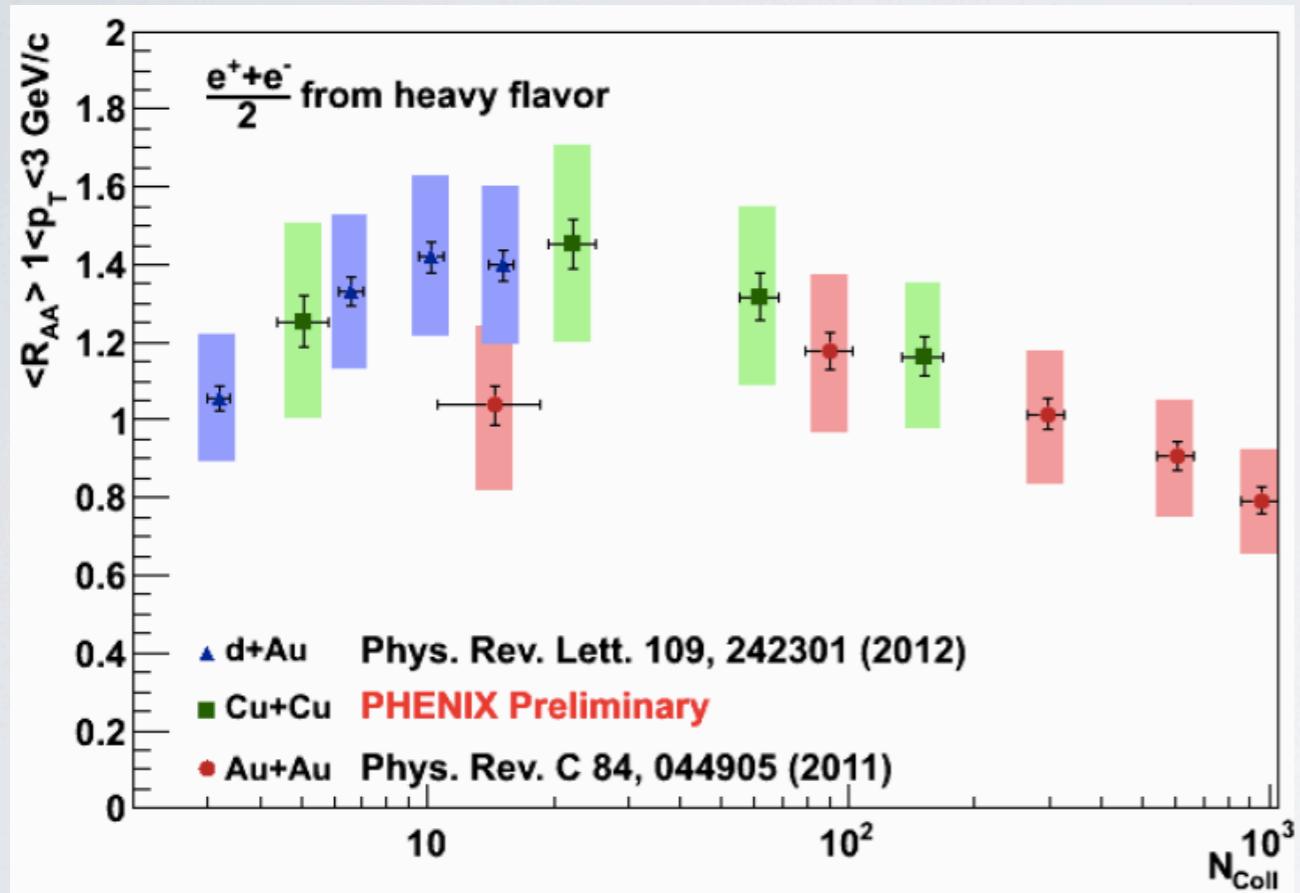
forward-rapidity



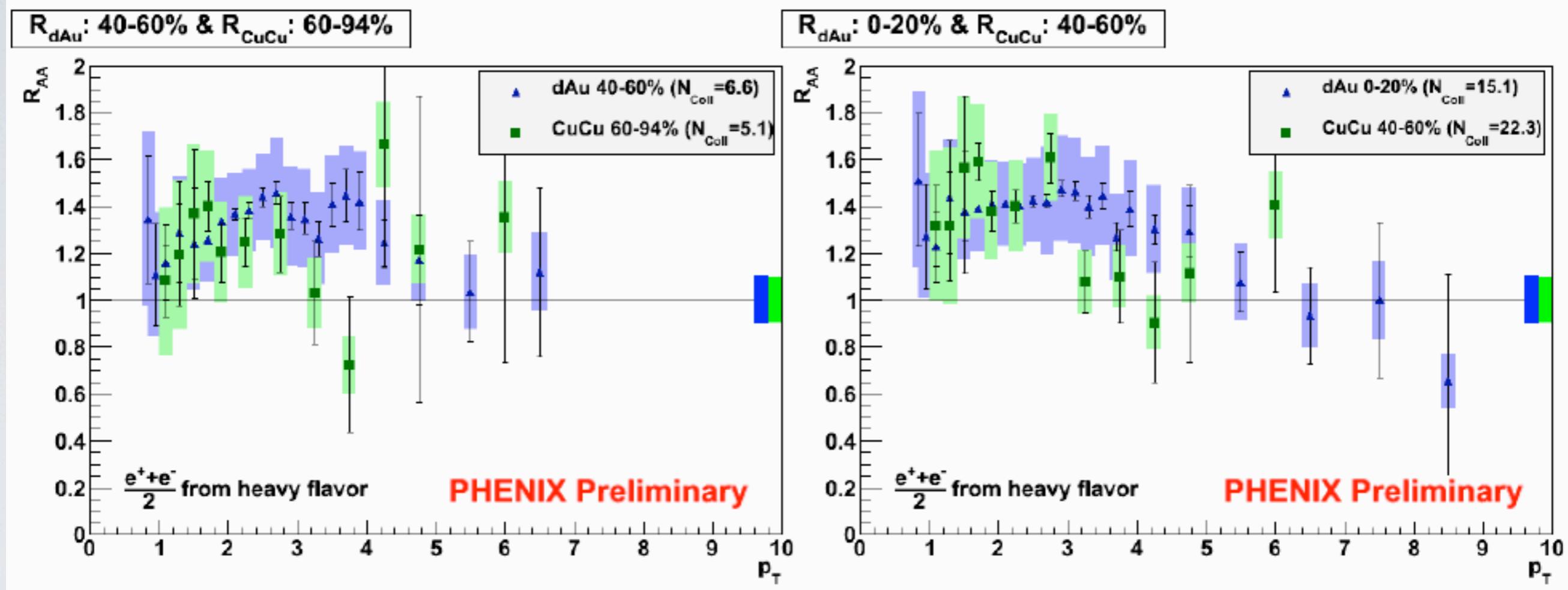
- Theoretical prediction works well!
  - consistent with  $Au+Au$  and over predicts suppression in  $Cu+Cu$  at mid-rapidity
  - consistent with  $d+Au$  and  $Cu+Cu$  at forward rapidity
- New PHENIX inner silicon vertex tracker system (VTX & FVTX) provides precise vertex position and allows to separate charm and bottom meson.

# **Back up**

# $R_{AA}$ vs. $N_{coll}$ at mid-rapidity



# comparison between d+Au and Cu+Cu



consistent in similar  $N_{coll}$  region